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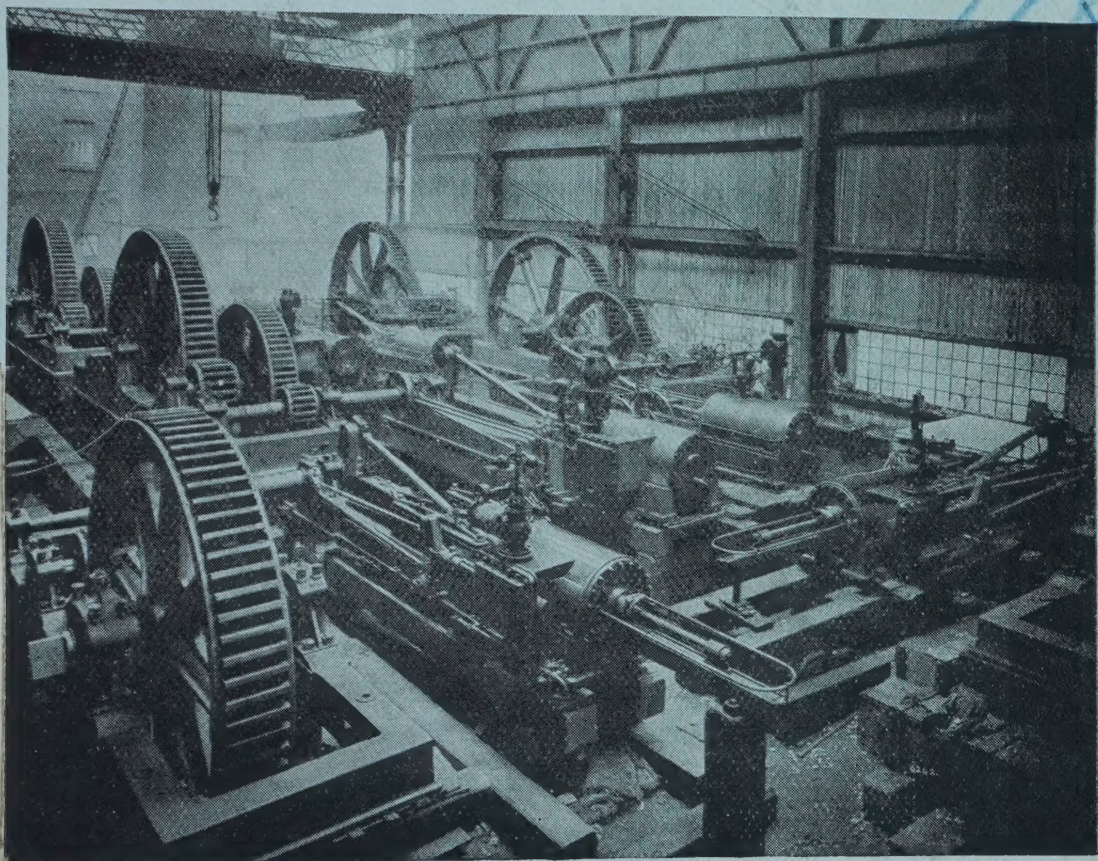
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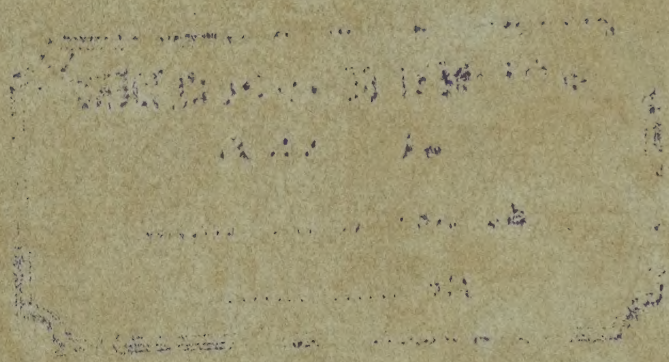
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SUGAR
AND
THE SUGAR CANE:

AN ELEMENTARY TREATISE ON THE AGRICULTURE
OF THE SUGAR CANE AND ON THE
MANUFACTURE OF CANE SUGAR.

BY
NOËL DEERR.

NORMAN RODGER,
ALTRINCHAM
(MANCHESTER).

1905.

[ENT. STA. HALL.]

PREFACE.

The object of the writer in publishing this elementary treatise is to present in one consecutive work a general view of the cane sugar industry. As there is no work in English covering this ground, he hopes that this may be of use to the English-speaking community connected with the cane sugar industry.

In compiling the information necessary, I have drawn on all available sources, and except for originality attaches to collecting and arranging data, but little is due to me.

I am especially indebted to Geerligs' papers in the *Sugar Cane*, dealing with the carbonatation process, with centrifugalling, and with the theory of molasses; Hausbrand's treatise on evaporation is a work which no one connected with the sugar industry can afford to dispense with; while for much information with regard to the diffusion process I am indebted to Spencer's well-known handbooks.

The originals of the coloured illustrations of the varieties of canes were made for me by Mr. S. R. Cochran; Messrs. Pott, Cassels and Williamson have supplied the blocks for Figs. 84, 86, and 89, and Messrs. Watson, Laidlaw & Co. those for Figs. 87 and 88. The drawings illustrative of the various forms of polariscopes have been supplied by Messrs. Baird & Tatlock.

My thanks are also due to Mr. Norman Rodger for undertaking the tedious task of passing my manuscript through the press.

As many readers will be aware, life on a sugar estate, remote from many social influences, is apt to become monotonous. The writing of this book has been for eight years the companion of its author's leisure moments. It is his hope that it may be of some use to others similarly placed to himself.

NOËL DEERR.

Blairmont, Berbice,
June, 1905.

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 ERRATA.

- Page 81, Line 4 from bottom.—For *Cercospara* read *Cercospora*.
 Page 103, Line 1.—For *balls* read *bolts*.
 Page 149, Line 6 from bottom.—For *there* read *this*.
 Page 168, Line 10 from bottom.—For *light* read *tight*.
 Page 223, Line 11.—For *seven* read *six*.
 Page 228, Line 14.—For *one ton* read *five tons*.
 Page 268, Line 3 from bottom.—For *537* read *589*.
 Page 268, Line 2 from bottom.—For *337* read *369*.
 Page 268, Last Line.—For *1500* read *1584*.
 Page 269, Line 2.—For *2421* read *2337*.
 Page 269, Line 3.—For *61.74%* read *59.85%*.
 Page 274, Line 19.—For *1591* read *1584*.

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SUGAR

AND THE

SUGAR CANE.

CHAPTER I.

THE CANE.

The sugar cane is a grass belonging to the natural order *Graminaceae*, family *Andropogoneae*; nearly related to the cane and also included in the same family is another sugar producer, the sorghum.

By most authorities all varieties of the cane are referred to a single species to which the name *Saccharum officinarum* is given; Cordemoy, however, classes the known varieties of the cane in three groups.

1. *Saccharum officinarum*, to which group belong practically all cultivated varieties of the cane.

2. *Saccharum violaceum*, canes with violet leaves occurring in Hawaii, none being of economic value.

3. *Saccharum sinense*, or the Chinese cane.

To these groups might be added a fourth variety, the Japanese cane which Stubbs (*The Sugar Cane*, p. 73) thinks may be a different species.

The complete cane may be divided into the root stock, the stalk, the flower and the leaves; the root stock may be either the mother cane (plant cane) or a prolongation of the stalk beneath the ground (ratoon or stubble). The roots of the cane are fibrous, lateral and very delicate; they ramify in the soil in all directions, generally extending from eighteen inches to three feet from the stem. Stubbs (*The Sugar Cane*, p. 13) says the roots do not penetrate very deeply, but Ling Roth (*Proc. Roy. Soc. New S. Wales*) mentions roots extending as far downwards as $4\frac{3}{4}$ feet, and Liversedge (*Proc. Roy. Soc. N. S. Wales*) states that he has seen roots as far down as 8 to 10 feet. The depth to which roots penetrate depends, however, largely on the nature of the soil, the roots extending furthest in light alluvial soils; in seasons of drought the roots extend downwards in search of water,

and in fields with a sour ill-drained subsoil the roots after penetrating downwards turn back on themselves to the upper surface soil. The cane has no tap root and its roots have little hold on the soil.

Roth (*loc. cit.*) distinguishes two forms of roots; the fine roots described above, and the fleshy roots which when a cane is planted appear to spring from the point of growth of the parent cane; the fine roots spring from a part of the parent cane described later. Roth thinks that the fleshy roots form the chief source of support to the plant.

The stalk of the cane, *i.e.*, the part above ground, is roughly cylindrical and differing widely in size, a variation due both to variety and to conditions of growth, the length extending from a minimum of two or three feet to a maximum of twenty feet; the diameter lies between the limits of one to three inches; the stalk is made up of a series of joints called the internodes (*f. Fig. 1*) separated from each other by

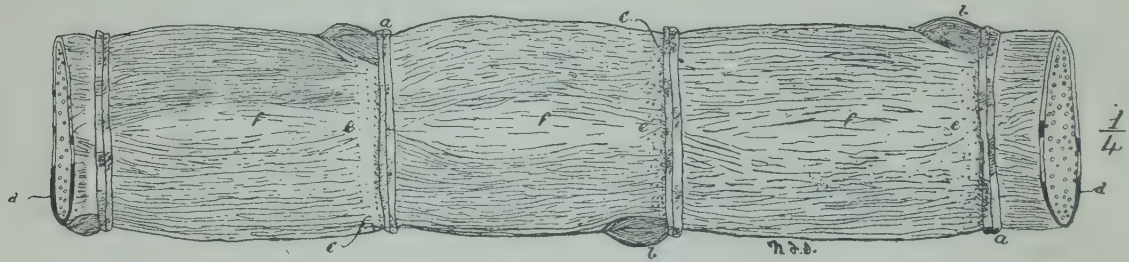


FIG. 1.

the joints or nodes (*e*); the length of the joints may be as much as eight inches, a length reduced by unfavourable conditions to as little as one inch; the nodes consist of a hard woody fibre and contain but little sugar, so that a cane with long joints is to be preferred to one with short ones; the number of joints varies from twenty to eighty.

The outer surface of the cane consists of the rind (*d. Fig. 1*); the rind may be red, white, yellow, green or purple, or striped in a combination of these colours. It is made up of three parts, the epidermis, the skin, and the rind proper; the rind is composed of sap vessels arranged parallel in a compact circle; at the nodes the rind divides into two parts, an inner and an outer rind, the former continuing to form the rind of the next joint; the sap vessels of the outer rind unite with others from the interior of the cane to form the leaf, upon which the skin and epidermis also continue. The skin overlies the

rind; in the young cane it is colourless, but afterwards it assumes the peculiar colour of the variety. The epidermis is very thin and transparent and nearly always white.

The rind is frequently covered with a bluish-grey substance of a waxy consistence called cerosin or cane wax; this substance is not a wax proper but belongs to the group of bodies known as alcohols. The leaves of the cane are alternate, one at each joint, and from three to four feet long; in colour they are varying shades of green, but some Pacific Island canes have purple leaves, and the Purple Ribbon cane of Queensland, known as Port Mackay in Mauritius, frequently develops variegated or entirely white leaves. The leaves taper towards the top and are delicately serrated along the margin; often they are ciliated at the base and sides; they are traversed longitudinally by a number of veins. The midrib is generally white, and sometimes red or purple; the leaves closely embrace the stalk until they wither and droop. It is through the leaf that the cane obtains its food.

Underneath each leaf and at the joint is the eye of the cane (*b. Fig. 1*); the eye is an embryonic cane, and it is by means of this eye that the cane is propagated; it is the size of a pea or larger, and may be oval, pointed or triangular; it is covered by a resinous substance and several layers of protective tissue. The eye contains a large store of nitrogenous matter destined for the use of the young plant.

Round each joint appears a ring of whitish semi-opaque spots; this part of the cane is called the zone of adventitious roots, each spot being an embryonic root; in wet weather those spots near the ground throw out roots, the eye at the same time developing; this development leads to a general weakening of the plant, and canes in which this occurs generally afford a poor juice.

The flower of the cane, commonly called the arrow, consists of large white or grey compound clusters, a panicle of soft silky spikelets being carried on an elongated peduncle. The spikelets are made up of three scale leaves, two exterior and one interior; the two former are called the glumes, and the latter the palea. Within the glumes and palea is the flower consisting of stamen and pistil only; the stamens are three in number; the ovary is ovoid and sessile, and contains only one ovule; it carries two styles of a reddish colour, which in turn carry a large number of stigmas. It is only exceptionally that the seed of the cane is fertile, and some varieties never

flower and others only in the tropics; the time of flowering varies from eight to fifteen months, and is usually about twelve months. The cane is not ripe at the time of flowering, maturity being delayed to two or three months afterwards.

If a section of a ripe sugar cane be made perpendicular to the axis and examined under a magnification of one hundred diameters the matrix of the cane is seen to be composed of large numbers of polygonal cells (*a. Fig. 2*); these cells are called the pith cells, and in them is contained the greater part of the sugar of the cane; a longitudinal

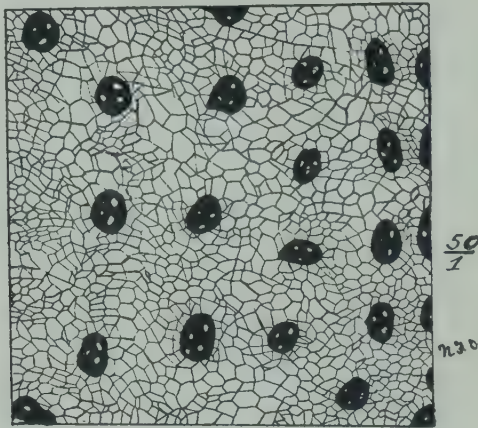


FIG. 2.

section through the cane (*Fig. 3*) shows the cells to be somewhat longer than wide. Distributed through the pith cells are seen groups of tissue (the black spots in *Fig. 2*) which form what are known as the fibrovascular bundles; these are less frequent near the centre, and predominate at the rind. At the nodes the pith cells disappear entirely, their places being taken by the fibrovascular bundles.

These latter are shown very highly magnified in *Fig. 4*; the vessels are shown at *c*, and at *d* are sieve tubes; the dark space surrounding the vessels and sieve tubes comprises thick walled woody cells which give strength and rigidity to the cane.

In *Fig. 3* all the above are shown in longitudinal section; in the internodes the fibrovascular bundles run parallel to each other, and have no communication, joining and establishing communication however at the nodes; the sieve tubes (*d*) are much larger than the pith cells, and are divided at intervals by partition walls.

In the life of the plant, water carrying food material passes upwards from the roots through the vessels to the leaves; in the

leaf it goes through certain processes and passes down through the sieve tubes to be distributed through the plant.

The juice contained in the cane is really of a twofold nature; that in the pith cells and that in the cells of the fibrovascular bundles. Under moderate pressures only the richer juice in the soft pith cells is expressed, the cells in the fibrovascular bundles being only ruptured under greater pressures; in this lies the explanation of the well known fact that the juice of the second mill is always poorer than that of the first. A third kind of juice exists in the cane, that contained in the vessels; this, strictly speaking, is not juice but water charged with food material on its way to the leaves. After rains these vessels are fully charged, and consequently canes cut after rains generally give a poor juice.

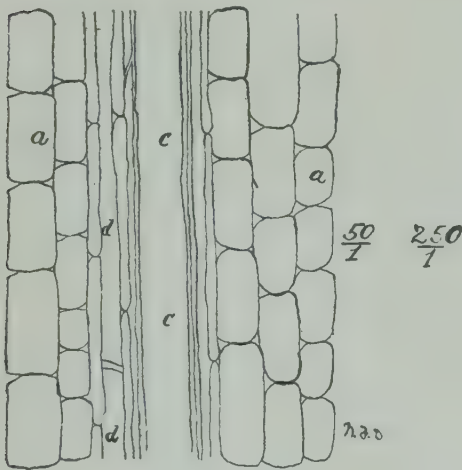


FIG. 3.

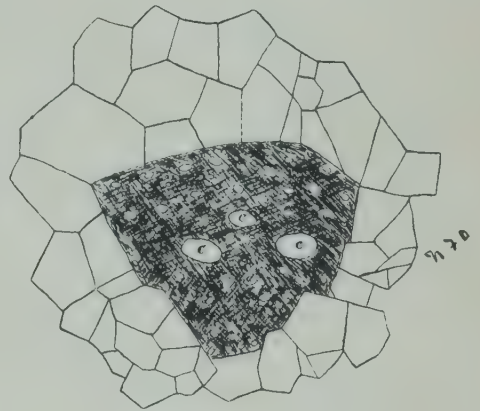


FIG. 4.

As already mentioned food material carried up through the vessels is elaborated in the leaf; during the day, in direct sunlight, starch is formed under the influence of bodies known as chlorophyll granules; during the night the starch formed is carried away and either used up for the immediate needs of the plant, or else stored as a reserve of food. In the case of the beetroot, the sugar cane, the sorghum, the pine apple, and other plants, this reserve takes the form of sugar; in all probability it is stored up to be used during flowering and subsequent ripening of seed. The wild sugar cane probably used its sugar in this way; but the cultivated variety, owing to its having been propagated by cuttings through countless generations, has in great part lost the property of bearing seed or flowering; its original habit still however remains.

The cane is not by any means of even approximately uniform composition but varies with species and conditions of growth. The limits of composition of ripe cane may be estimated as:—Water, 69% to 75%; sugar, 10% to 18%; glucose, 0% to 2%; fibre, 8% to 16%; ash, .3% to .8%; organic non-sugar, .5% to 1%; what is here called fibre refers to the insoluble matter and not to true cellulose. In analyses made at Audubon Park the true cellulose was found to be a little under 5%, and Geerligs has found the xylan or wood gum returned generally in analysis as fibre to be 25% to 30% of the whole fibre. Payen found the cane and leaves to contain .090% nitrogen; Ross, quoted in Stubbs' *The Sugar Cane*, found full grown cane, though far from maturity, to contain in albuminoids stalks .62%, tops and leaves 1.78%, the canes including tops and leaves containing 1.03%; the writer found a crop of 50,000 tons of cane as they reached the factory to contain .045% nitrogen.

The percentage of sugar in a cane though perhaps to some extent dependent upon variety is by no means entirely so; in Demerara where up to 1900 practically the whole crop consisted of the Bourbon variety, canes grown on virgin forest soil gave very heavy crops with generally less than 11% of sugar, the sugar percentage of canes grown on older land often rising to 14% or more.

As an instance of variety affecting composition, the Jamaica Elephant cane which invariably gives a poor juice may be quoted, and the seedling canes produced in the Demerara Botanical Gardens, notably No. 74, show some evidence of high sugar content as being an inherent property of the variety. On the whole, however, conditions of growth are the main factors which determine the sweetness of the cane.

The composition of the cane is not uniform throughout its length as the annexed table of analyses by Bonâme will show.

- A. Plant cane, imperfectly ripe and still in full vegetation.
- B. Second ratoons, 11 months old.
- C. Fourth ratoons in vegetation.
- D. First ratoons, 11 months old.
- E. Creole cane, the stalk 1 metre long and 10 cm. in circumference.
- F. Plant cane, very ripe, 14 months old.

	Degree Beaumé.	Sugar Per cent.	Glucose Per cent.
A. Lower part	9.05 ..	13.74 ..	1.78
Middle „ .. .	9.5 ..	14.11 ..	2.44
Upper „ .. .	8.2 ..	8.85 ..	4.11
White top .. .	7.5 ..	4.01 ..	6.57
B. Lower third .. .	— ..	16.20 ..	.94
Middle „ .. .	— ..	15.40 ..	1.59
Upper „ .. .	— ..	13.60 ..	1.75
C. White top .. .	— ..	9.07 ..	1.95
Upper part .. .	— ..	16.52 ..	.78
Lower „ .. .	— ..	19.44 ..	.37
D. Lowest fourth .. .	11.1 ..	20.73 ..	.37
Lower middle fourth .. .	11.1 ..	20.41 ..	.37
Upper „ „ .. .	10.7 ..	19.44 ..	.65
Upper fourth .. .	10.4 ..	17.82 ..	.52
White top .. .	9.2 ..	14.90 ..	.71
E. Lower third .. .	— ..	8.74 ..	3.56
Middle „ .. .	— ..	1.24 ..	4.38
Upper „ .. .	— ..	4.62 ..	4.56
F. Lowest fourth .. .	12.3 ..	22.68 ..	.51
Lower middle fourth .. .	12.3 ..	22.68 ..	.52
Upper „ „ .. .	12.3 ..	22.68 ..	.52
Upper fourth .. .	12.0 ..	22.03 ..	.53
White top .. .	10.0 ..	16.84 ..	.70

The variation in composition of the juice in the nodes and internodes is given by Bonâme.

Nodes {	Sugar .. .	13.34 ..	12.74 ..	16.73
	Glucose .. .	.29 ..	.28 ..	.31
Internodes {	Sugar .. .	16.51 ..	16.80 ..	19.72
	Glucose .. .	.60 ..	.84 ..	.48

Stubbs gives the following as the result of analyses of twenty stalks of purple cane:—

	Degree Brix.	Sugar.	Glucose.	Solids not Sugar.	Fibre.
Nodes .. .	15.94 ..	12.6 ..	.13 ..	3.21 ..	16.5
Internodes .. .	17.40 ..	11.5 ..	.94 ..	.96 ..	8.00

The great variation in composition of juice at nodes and internodes is well shown in the tables quoted above and an explanation given of the decreased sugar content of second mill juice compared with first mill juice.

CHAPTER II.

THE RANGE OF SOILS AND CLIMATE SUITED FOR THE CANE.

The sugar cane is essentially a tropical plant and reaches its maximum perfection in those countries which have a mean average temperature of 75° F. to 85° F. combined with a rainfall of 80 to 100 inches per annum, or in the absence of the latter, an ample supply of water for irrigation purposes.

The extreme limits for the cane are the South of Spain (36° to 37° N.) and Japan (30° to 35° N.) on the one side, and Cape Colony (29° – 30° S.) and New Zealand (35° – 37° S.) on the other; the countries where the cane succeeds best are perhaps Java (6° N.), Hawaii (20° N.), British Guiana (6° N.), Cuba (22° N.), and North Peru (5° S.). Other countries where the cane is a staple product are the West Indies (10° – 20° N.), Queensland, New South Wales (10° – 20° S.), Central America (8° – 20° N.), Brazil (0° – 20° S.), Philippines (5° – 15° N.), Louisiana (30° N.), Natal (30° S.), Mauritius and Bourbon (20° – 22° S.); certain of these countries, for example Louisiana, Natal, Queensland, are only able to produce sugar at a profit when aided by heavy protective duties.

After temperature the most important climatic influence is rainfall. Stubbs says that an annual rainfall of about sixty inches per annum is most advantageous and that this should be distributed over ninety to one hundred days; of this about forty-five inches should fall in the wet, and the remainder in the dry season. In British Guiana a rainfall of sixty-five inches is very low and would result in poor crops of cane; a rainfall there of ninety to one hundred inches gives very heavy crops of cane, with a juice of low sugar content. In the dry Hawaiian Islands rain often fails for a year, and in Peru it never falls; in those countries water is supplied by irrigation and very heavy crops of sweet cane are grown, the cane being artificially ripened by withholding water two or three months before harvesting.

Another point of importance is the humidity of the air, evaporation from the leaves and soil taking place less rapidly when the air is saturated with moisture than when the air is dry; for this reason districts near the sea over which breezes saturated with moisture blow can be successfully cultivated with a less rainfall than others where the atmosphere is drier.

Provided all the elements of fertility are present in the soil, the cane grows best on those soils that are capable of retaining a large quantity of water; such soils are clays and heavy loams. Light loams and sandy soils do not retain a sufficient quantity of moisture to meet the requirements of the cane, and in seasons of only moderate dryness cane grown on such soils is liable to suffer, and indeed cannot be properly cultivated unless aided by a system of irrigation. The soils of Hawaii are volcanic loams of exceptional fertility and here, aided by irrigation, the maximum crops are grown. Another class of soil which suits the cane well are the alluvial deposits containing a larger proportion of vegetable matter, such as are found in the virgin soils of Demerara; these soils contain large quantities of potash and the ash of the cane is also particularly rich in this material; in soils of this nature good drainage is of the first importance.

Delteil, a French authority on tropical agriculture, says: "In mellow open soils, watered by rain or irrigation, the cane becomes fine and large and gives much sugar. In light, sandy soils, or in volcanic soils of recent origin, the juice is very sweet, but the canes are somewhat small.

"In calcareous soils, the canes develop superlatively well, the juice is rich and easy to work. In alluvial soils, too moist or too rich in alkalies, the canes have a fine appearance, but the juices are poor in sugar, work with difficulty and produce much molasses."

Krüger says: "The sugar cane loves a loose, well disintegrated, well ventilated, yet settled soil."

The three mineral constituents of soils that are of primary importance to the cane are lime, potash, and phosphoric acid. Dr. Maxwell, the Hawaiian and Queensland expert, lays great stress on the necessity for an ample supply of lime, and in an address delivered in 1903 to a Meeting of Queensland planters, seemed to consider a supply of this material of more importance than one of phosphoric acid.

Below are given a number of analyses of sugar-cane soils collected from various sources :—

Island.	Lime. Per cent.	Potash. Per cent.	Phosphoric Acid. Per cent.	Nitrogen. Per cent.
Oahu	·380	·342	·257	·176
Kauai	·418	·309	·187	·227
Maui	·396	·357	·270	·388
Hawaii	·185	·346	·513	·540

The above figures are the mean results based on nearly one hundred analyses by Dr. Maxwell, and illustrate the enormous fertility of the Sandwich Islands.

LOUISIANA SOILS.

Insoluble Mat- ter per cent.	Potash per cent.	Soda per cent.	Lime per cent.	Magnesia per cent.	Iron Acid per cent.	Phosphoric Acid per cent.	Sulphuric Acid per cent.	Organic Matter per cent.	Nitrogen per cent.
88·720	·092	·158	·394	·087	1·12	·068	·028	2·96	·097
83·680	·162	·142	·313	·025	6·33	·126	·046	4·10	·130
86·516	·233	·081	1·494	·039	6·822	·098	·043	1·90	·060
62·550	·747	·181	·910	1·361	13·444	·146	—	6·65	·085

The above are of Louisiana soils, quoted by Stubbs in *Sugar Cane*. He concludes that the average composition of Louisiana soils is lime ·5 per cent., potash ·4 per cent., phosphoric acid ·1 per cent., nitrogen ·1 per cent.

These soils might be classed as being comparatively weak in phosphoric acid and nitrogen, but yet of a high degree of fertility.

JAVA SOILS.

Sand per cent.	Calcium Car- bonate per cent.	Lime per cent.	Magnesia per cent.	Potash per cent.	Phos- phoric Acid per cent.	Sul- phuric Acid per cent.	Nitrogen per cent.
9·6	1·38	2·52	·18	·14	·19	·025	·08
26·2	·02	·95	·19	·12	·11	·04	·07
53·4	·02	2·21	·17	·06	·07	·023	·06
40·2	·05	2·48	·26	·05	·07	·032	·14
45·6	·00	1·08	·17	·05	·04	·04	·03
4·2	·02	·68	·10	·05	·06	·033	·09

These analyses of Java soils were made by Kramers, and quoted by Krüger in *Das Zuckerrohr*. These soils are exceptionally rich in lime, but the potash, phosphoric acid and nitrogen are distinctly on the low side.

Moisture.	Organic Matter and Combined Water.	Silica and Silicate of Alumina.	Lime.	Magnesia.	Sulphuric Acid.	Phosphoric Acid.	Potash and Soda.	Chlorine.	Oxide of Iron.
26·00	5·90	61·68	·64	·50	·01	·08	·11	Trace	5·08
23·00	5·30	64·44	·11	·36	Trace	·05	·10	·02	6·62
23·10	12·56	41·42	·56	·26	·04	·06	·20	·02	21·78
3·50	6·66*	..	·27	·15	·18	·19	·50	·005	11·17
5·62	34·24†	..	·28	·17	·89	·19	·53	·006	2·40

* Containing nitrogen ·049. † Containing nitrogen ·973.

The first two analyses above are of Demerara soils made by Phipson and quoted by Lock and Newlands in their treatise on sugar; the first had been in cultivation for five and the second for upwards of sixty years; the third is an analysis from the same source of a red Queensland soil; the fourth and fifth are analyses by the writer of soils in Berbice; the fourth is of a heavy clay which had been in cultivation for a number of years and the fifth is of a virgin forest soil.

An analysis of a Philippine soil made by Harland and quoted by Krüger in *Das Zuckerrohr* was as follows:—

Silicious Matter.	Alumina.	Ferrie Oxide.	Magnesia.	Potash and Soda as Chlorides.	Lime.	Manganese Oxide.	Sulphuric Acid.	Phosphoric Acid.	Organic Matter.
53.39	13.16	4.80	.42	1.14	1.60	.10	.09	.25	25.05

The following are four analyses of Mauritius soils made by the writer:—

Lime.	Potash.	Phosphoric Acid.	Potash Soluble in 1 per cent. Citric Acid.	Phosphoric Acid Soluble in 1 per cent. Citric Acid.
.419	.199	.156	.0092	.0031
.475	.188	.129	.0186	Trace
.389	.155	.105	.0143	Trace
.163	.121	.221	.0242	.0020

CHAPTER III.

THE VARIETIES OF THE SUGAR CANE.

Stubbs (*Sugar Cane*) remarks that the nomenclature of the varieties of the cane is execrable, and indeed the subject is in an almost hopeless state of confusion, although good work has been done at several botanical stations towards a systematic classification. What tends towards confusion in the nomenclature is that a cane introduced from one country into another immediately receives a new name, generally connecting it with the country from which it came; thus the White Transparent is also known in Trinidad as Caledonian Queen, its origin being traced to New Caledonia. In Louisiana this cane is called Light Java, having been imported from the latter country. In other cases a cane is called after its introducer, a method of nomenclature which, while serving the purpose of perpetuating the memory of eminent planters, gives no information as to its origin and characteristics. A third method is the use of local native names—a method not to be recommended, as the Javanese, Polynesian, and other languages used are not generally understood. The fourth and best method of classifying canes is by their outward characteristics, especially their colour.

Most of the older writers classified canes according to the countries of their origin, and following them we have:—

1. *Pacific Islands Canes*.—The Pacific Islands are generally supposed to be the original home of the cane, and two well known varieties are so perpetuated, the yellow, and the purple striped, Otaheite; both of these have become widely disseminated and appear under different names all over the tropics. The yellow Otaheite is perhaps the Bourbon and the purple striped possibly the Cheribon; these canes are referred to further on. A number of Pacific Islands canes have been described by Cuzent; these are mentioned here as they sometimes occur in the literature of the cane.

(a.) To Uti, a violet cane, not indigenous but introduced from Java.

(b.) Rurutu, a light violet cane.

(c.) Irimotu, a green cane remarkable for carrying a large amount of setae or hairs.

(d.) Oura, a yellow and violet ribbon cane.

(e.) Piavere, a light red cane.

(f.) Uouo, a white cane.

(g.) Toavae, a yellow and green ribbon cane.

2. *Java or Batavian Canes*.—A large number of native Java canes, distinguished by the native term Tibboo, appear in the literature, many being apparently the same cane with different names. Of the native names which appear in the literature may be mentioned the Tibboo Mouget, said by Raoul to be the Cheribon cane; the Tibboo Mird, classed by Stubbs as identical with the Light Java; the Tibboo Soerat, which appears to be the yellow violet Java ribbon or Cheribon cane; and the Tibboo Etam, the Black Java or Black Tanna; the word Tanna is Javanese and denotes ‘rich earth.’ A Tanna cane is one which, according to native Javanese experience, requires a rich soil.

3. *Indian Canes*.—An endless list of native terms might be given, as well as of canes native to the Straits. Of better known varieties may be mentioned—

(a.) The Salangore, which is perhaps the White Transparent.

(b.) The Samsara, a greenish cane lately introduced as a sugar producer into the West Indies.

(c.) The Namala, a green and red ribbon cane.

(d.) The Keli, a white cane.

(e.) The Kulloa or Kullore, a large red cane, probably identical with the Tibboo Meerah or Assam cane, also grown in the Malacca Peninsula.

4. Amongst other varieties classed as to country of origin may be mentioned the Cochin China Elephant, the Chinese cane, and the Japanese cane. None of these are good sugar producers; the Chinese cane is grown in Northern India, and the Japanese cane in Japan; the latter is stated by Stubbs to be a moderate sugar producer, extremely hardy, and enormously productive, with high fibre content.

The best method of classifying canes is according to their outward characteristics, and this method has been adopted by Harrison and

Jenman, and by Stubbs. The two former (*Report of the British Guiana Botanical Gardens, 1890; Sugar Cane, No. 273,*) divide the varieties in cultivation at the Georgetown Botanical Gardens into five classes, the following list being abstracted from that report:—

(a.) *Yellow-Green or Green Canes*, often blotched with red, including—

Bourbon, with which is synonymous Bamboo II., China II., Colony, Cuban, Lahaina, Otaheite.

Keni Keni.—Near the Bourbon, but a much shorter cane.

Elephant (Jamaica).—This is an entirely different cane from the true Elephant.

Singapore.—Somewhat resembling the Bourbon, but with distinct characteristics.

Lakona.—A pretty species, like a thin Bourbon, but of brighter yellow colour; synonymous with Jamaica Sacuri.

Kamba-Kamba-Vati.—Canes numerous, slender, less than medium height.

Barbados Native.—Synonymous with West Indian Creole.

Honolulu.—Canes numerous, erect, forming good bunches, under average length.

Sacuri.—Rather short and thin, very like Honolulu.

Ko-poa-pa.—Very dwarfed in size, only about a foot long.

Chicaga.—Rather under average length, and length of node; of average girth.

China.—Of average girth, less than average height and length of node.

Meli geli.—Medium height, girth, number to the stool and length of internodes; synonymous with Bamboo I. and III., and Demerara.

Morris.—Apparently a variety nearly identical with Meligeli.

(b.) *White, Vinous, and Brown-tinged Canes.*

Burke.—Of average length, girth, and length of internodes.

Selangore.—Rather under average height, of nearly average girth, much under average length of internodes; synonymous with White Mauritius.

Tamarind.*—Of average height and girth, usually less than average length of internodes.

* The cane known as Tamarind in Mauritius is a dark olive green cane blotched with brown, and with swollen nodes.

(c.) *Grey and Pink-tinged Canes.*

Elephant.—Of full average length and length of internodes, much over average girth.

White Transparent.—Of full average length, hardly of full average girth, colour at first pink, finally a grey horn tinge in lower part and yellow-tinged with pink in upper half; rarely blotched with carmine when sun exposed. Synonymous with Caledonian Queen, Mamuri, Rappoe.

(d.) *Ribbon Canes.*

Red Ribbon.—Of full average length, barely full average girth, long internodes. Colour in part pink or greyish, and in part striped pink or claret or yellow. Synonymous with Seete, Striped Singapore.

Violet Ribbon.—Under average length and length of internodes, of full average girth. Colour partly white and partly violet, and sometimes light green, with pink or violet stripes.

Green Ribbon.—Of full average length, girth and length of internodes; colour striped in cream and pale green, often taking a pinkish tint with age.

Drard.—Under average length and girth, of average length of internodes; colour bright straw-yellow with faint signs of longitudinal striping (yellow and very pale green).

Large Green.—Only two, three or four feet length of cane, girth nearly or quite up to average, length of internodes much under; colour green with faint dark and green striping.

Vagabonde.—Four to six feet of hard cane; $\frac{3}{4}$ to 1 inch diameter, internodes average length; colour striped conspicuously, but in varying width of band, dark claret and bright green.

Grand Savanne.—Of nearly average length, of average girth and length of internodes; in colour pale, faintly striped, variably light dull straw and very pale green, the latter being indistinct.

Batramic.—Under average length and girth, of average length of internodes; colour, green with chocolate stripes of varying width.

Horne.—Less than average length, of average girth or under; colour variable, unequally and indistinctly striped in very pale green, darker green, or bronze, or brown, or pale claret.

Samuri.—Under average length, nearly average girth, average length of internodes or over; colour dark purple, inconspicuously yet definitely striped with lighter hues.



FIG. 6.
LAHAINA.

3
4
SIZE

Vulu Vulu.—Of average girth, length, and length of internodes; colour variable, striped variably in dark or pale brown (with a tinge of pale claret in the colour) and dark claret.

Vico.—Less than average length (4-5 feet), much less than average girth (largest only the size of a stout walking stick); very faintly striped.

Po-a-ole.—Of full average height, girth and length of internodes; colour bright reddish claret, very faintly striped. Synonymous with Jamaica and Barbados purple Mauritius.

(e.) *Claret and purple canes.*

Mani.—Of average height, girth and length of internodes; colour very pale claret with bronze tint. Synonymous with Norman. A paler cane than Po-a-ole, but of about equal size.

Vitua-huala.—Under average length and girth, nearly average length of internodes; colour a pale claret bronze.

Hillii.—Medium height, some much below others, up to medium girth, internodes usually long; colour bronze pink (kind of neutral tint).

Purple Transparent.—Full average length, barely average girth, full or over average length of internodes; colour at first purplish, finally claret and stone gray. Synonymous with Java, Purple Mauritius, Queensland Creole, Meera.

Boisrouge.—Much under average height (about 4 feet of cane), under average girth, internodes variable, usually over average length; colour a pinkish-horn tinge, deeply stained with variable size dark dot-like blotches. Synonymous with Bouronappa.

Keening.—Much below average length and girth (3-4 feet length), internodes less than average length; colour at first claret, at length pinkish, always blotched with dark blackish patches. Synonymous with Naga.

Kara-Kar-awa.—Of barely medium height, colour purple turning claret eventually.

Brekeret.—Of medium height, purple turning dark claret.

Nara Tara.—Of medium height, over medium girth, internodes variable, short or moderately long; colour very dark purple with greyish bloom.

Governor Lees.—Of average length and girth, but hardly so in length of internodes; colour purplish or claret, with slight greyish tinge towards the nodes, reaching vinous horn shade finally.

Russel.—Under average length and length of internodes, up to average girth; colour purple primrose, finally turning vinous grey.

Dama.—Of medium height, girth and length of internodes; colour passing from a pale claret to a dingy metallic stone grey.

Stubbs in his work *The Sugar Cane* only recognises three classes of canes, in distinction to the five divisions of Harrison & Jenman. His divisions are:—

- (a.) White, yellow, and green canes.
- (b.) Striped canes.
- (c.) Solid colours other than in (a.).

In the first division he includes a group of identical canes: La Pice, Panachee, Le Sassier, Tibboo Mird, Bourbon, Crystallina, Green, Light Java, and Hope, introduced into Louisiana from Java. The inclusion of the Bourbon in this category is remarkable, and in a letter the writer received from Dr. Stubbs in 1903, he says—"I have long since been convinced that the Bourbon cane which I have is not the Bourbon alluded to by several of the correspondents. . . . I am almost persuaded that the Otaheite and the Bourbon are the same cane, probably differentiating a little by separate cultivation, and that your* Lousier is our Otaheite." The nomenclature of this very important variety will be referred to again.

In the second group of this class appear the Yellow, the Otaheite, and the Lousier, which Stubbs states are almost identical; their origin being Tahiti, he suggests the name White Tahiti for them; they are mentioned as fairly good canes, ratooning well, but with juice containing a high proportion of solids not sugar.

In the third group appear the Portier, Lahaina, and Keni-Keni, which are stated to be identical. (In the Demerara classification Bourbon was classed as synonymous with Lahaina and Otaheite; and Keni-Keni as distinct from the Bourbon.) They are stated to be bad ratooners, with a fair sugar content, likely to succeed as plant cane and originating from the Marquesas Islands.

In the fourth group are the China cane and Green Elephant; these are perhaps the same as the Jamaica Elephant and Cochin China Elephant.

In the fifth group appear the Rose Bamboo, the Salangore† and Vulu Vulu, which are stated not to be identical, but to have peculiar

* Mauritius.

† A. T. Robinson, in a paper read before the Mauritius Chamber of Commerce, 1898, states that the Salangore is very similar to the Lousier.

characteristic parallel streaks of a brownish colour on the more mature joints.

In the sixth group are given two Hawaiian canes, the Pupula and the Kakea, green canes with faint pink stripes on the more mature joints, and both of great promise; other canes in this class are the Creole cane introduced into Louisiana by the Jesuits from the Malabar coast, the Japanese cane already noted, and the Kulloa* (or Kullore) or Bamboo cane.

In the second class of striped canes are included three identical canes, the Malay, Brisbane, and Green Rose Ribbon; these canes are striped green and rose, and are stated to be classed in Mauritius as canes of first merit; at the present time (1903) no canes answering this description are cultivated in Mauritius.

In the second class appear the identical canes, Red Ribbon, Mexican Striped, Batavian, Home Ribbon, coming originally from Tahiti and also known as the Otaheite Ribbon; this cane appears identical with that known in Java as the Cheribon, and in Mauritius as Striped Tanna or Tanna Rayée.

In the third class appear four canes, the Tsimbic, Isaquia, Vituahuala and Horne, characterised by a red stripe on a yellowish background; the Tsimbic is a native of New Caledonia and the origin of the others is not stated; the Horne is, however, a bud variation from the Lousier of Mauritius origin, discovered by Mr. John Horne, one time Director of Forests and Gardens in that island, and is interesting as being perhaps the first recorded bud variety. It has been stated that solid coloured canes do not throw sports; in Mauritius the phenomenon is well known and the writer has not infrequently observed a yellow green striped sport and a sport similar to the Horne and in fact a Horne cane coming from a Lousier stool. This cane, which in Mauritius is also called Lousier Rayée, is cultivated there to a fair extent.

In the next group appear the Ainakea, Kainio, and Nikilolo Light Striped; the two first came to Louisiana from Mauritius, viâ Hawaii. The Kainio and Nikilolo Light Striped are red striped on a green back ground, and the Ainakea striped yellow on green. The Kainio is said to be called in Mauritius the Light Bourbon, and the Ainakea the Dark Bourbon. The description of these canes corresponds to two canes known in Mauritius as Lousier (= Bourbon) Rayée, making three canes known there as Lousier Rayée.

* This cane is sometimes referred to as "The Red Cane of Bengal."

In the next group are two Hawaiian canes, striped dark and light purple, the Aikilolo Dark Striped and the Manulete; and in another group are the Cavengerie, introduced into Louisiana from Mauritius viâ Cuba, the Po-a-ole, and the Altamattie, described as large red canes with a faint black stripe; these three are stated to be identical. The Cavengerie, once largely grown in Mauritius, is now abandoned there.

In his third class Stubbs places all solid coloured canes other than those in the first class. In the first group are the Norman, Savanne, and Naga canes approaching the Japanese cane. Harrison & Jenman put the Mani as equivalent to the Norman and class the Grand Savanne as a ribbon cane. In a group by itself is the Black Java, identical with the Louisiana Purple, a bud variety from the Home Ribbon; this cane is known in Mauritius and elsewhere as the Black Tanna. The remaining canes in this class are not of great importance; they include the Brekeret and Marabal, two similar canes of purple colour with enlarged internodes and reddish yellow pith, the Purple Elephant from Cochin China, and the Ohio, Honuaula, Papaa, Cuapa, and Liguanea, the three first of Hawaiian and the two latter probably of Polynesian origin.

In an article in the *Demerara Argosy*, July, 1897, are given the synonyms of some canes grown in the Demerara Botanical Gardens. In that list, in addition to some synonyms given above, are found—

Bourbon = Lahaina = Otaheite = Lousier = Portier; the Lahaina Portier, and Keni-Keni are given as identical by Stubbs, but distinct from the Otaheite and Lousier.

White Transparent = Cheribon = Hope = Light Java. This identity connects the well-known White Transparent with the first cane in Stubbs' classification; the Crystallina, one of Stubbs' synonyms is given as identical with Rose Bamboo, Blue Cane, Light Purple, and Stubbs again puts the Rose Bamboo, Salangore, and Vulu Vulu in a different group; this is a typical instance of the confusion* in nomenclature which has arisen. The Cheribon, included above as a synonym, is also probably erroneous; the Cheribon cane of Java is the Yellow Violet Ribbon, also known as Striped Tanna.

Raoul, in "*Le Manuel des cultures tropicales*" mentions some cases not already included; amongst these are as synonymous terms—

* In this case the confusion is perhaps due to the very different appearance the cane presents at different periods of growth and when grown under different conditions. Fig. 12 is a Rose Bamboo from Mauritius, exactly similar to a ripe White Transparent of Demerara.

Yellow Tahiti, To avae, Tebbou Otaheite, Bourbon, Tebbou Njamplong, Solera, Cayenne, Yellow Singapore; this cane is evidently the well known Bourbon already discussed, and as a similar but not identical cane he gives the White Tahiti.

In another group he describes as synonymous the Tebbou beltong berabou, Tebbou Cappar, Salangor, Penang, Chinese, Crystallina; this is apparently the White Transparent; under the name Selangor, L. Wray many years ago wrote of it as the best in the world. As further synonymous of the cane already mentioned as Striped Tanna, Home Ribbon, &c., Raoul gives the names To Oura, Tebbou Soerat, Guinghan and Maillard, and as identical with the Black Tanna or Black Java, the names Tebbou Mouget, Tebbou assep, Tebbou itam, Black Imperial, and Toute.

There are three varieties extensively grown in Mauritius not mentioned among the foregoing. They are: the White Tanna, a bud variation from the Striped Tanna (this cane is distinguished by its great length; the girth and length of internode is considerably above the average); the Escambine (= Tsimbic), a claret coloured long-jointed variety; and the Port Mackay, a dark claret cane with inconspicuous but well defined black stripes, also grown in Queensland under the name Purple Ribbon.

Coloured drawings of the principal varieties of cultivated canes, for which the writer is indebted to Mr. S. R. Cochran, are given in *Figs. 5-13**; they are *Fig. 5*, Bourbon; *Fig. 6*, Lahaina; *Fig. 7*, Striped Tanna; *Fig. 8*, Black Tanna; *Fig. 9*, White Tanna; *Fig. 10*, Escambine; *Fig. 11*, Port Mackay; *Fig. 12*, Rose Bamboo; *Fig. 13*, Striped Bamboo.

An article dealing with the varieties of canes as grown in Hawaii, and due to Mr. C. F. Eckart, throws considerable light on the points discussed above.

Mr. Eckart puts the Lahaina = Bourbon = Portier = Lousier, and the Rose Bamboo = White Transparent = Caledonian Queen = Rappoe, etc.

The slight differences which occur in these "varieties" Mr. Eckart attributes to their being cultivated in such varying conditions of soil and climate. To the cane known as Bourbon he attributes an origin in the Malabar coast, whence it travelled *viâ* Mauritius, Réunion, and Madagascar to the West Indies and the Pacific Islands; thence *viâ*

* See Coloured Plates.

Louisiana and the Marquesas Islands it reached the Hawaiian Islands under the name of Otaheite and Lahaina.

Mr. Eckart further says:—"White Bamboo, Queensland No. 7, Yellow Caledonia, and the unstriped cane which occasionally appears in a stool of Big Ribbon are closely allied; in fact between White Bamboo and Yellow Caledonia there appears to be no difference, and after four years' trial it is impossible to distinguish one from the other." From this it appears possible that the cane now so extensively grown in Mauritius under the name White Tanna, a sport from the Striped Tanna or Cheribon cane, may be closely allied to the Yellow Caledonia, etc., if not even actually identical with it.

The synonyms of the principal varieties of canes are collected below:—

BOURBON = Bamboo II. = China II. = Colony = Cuban = Lahaina = Otaheite not equal to Keni-Keni (Harrison & Jenman). Portier = Lahaina = Keni-Keni; Lousier = Otaheite = Yellow (Stubbs). Lahaina = Bourbon = Portier = Lousier (Eckart).

The following names may also be synonymous: To avae, Tibbou N'jamplong, Tibbou L'Cent, Solera, Cayenne.

WHITE TRANSPARENT.—Rappoe = Caledonian Queen* = Mamuri (Harrison & Jenman). La Pice = Crystallina = Green = Light Java = Hope = Panachee = Le Lassier = Tibbou Mird (Stubbs). Rose Bamboo = White Transparent = Caledonian Queen = Blue Cane = Light Purple = Rappoe = Mamuri = Hope = Light Java (Eckart). The Burke and Mont Blanc canes are probably identical with the above. Closely allied canes are Salangore, Vulu Vulu, and Grey Fiji.

BLACK TANNA.—Louisiana Purple = Black Java (Stubbs). Other names may be: Tibbou itam, Tibbou assep, Tibbou mouget, To ute.

STRIPED TANNA.—Mexican Striped = Red Ribbon = Home Ribbon = Batavian (Stubbs). Other synonyms are Cheribon, Java Yellow Violet, Otaheite Ribbon, Tibbou Soerat.

WHITE BAMBOO †.—Yellow Caledonia (Eckart) and perhaps White Tanna.

For very many years the cane was not supposed to bear fertile seed. Rumphius, a traveller of the seventeenth century, stated that

*The Cavengerie, a totally distinct cane, is in Mauritius occasionally confused with and called Caledonian Queen.

† The White Bamboo of Mauritius, once largely grown there, is of the Bourbon type, and distinguished by large quantities of cane wax.

the cane yielded seed when allowed to grow wild in stony places, and Bruce, in the following century, wrote that in Egypt cane was propagated by seed; both these observations were discredited. In 1859, Parris, in a letter in the *Barbados Advocate*, announced that he had seen self-sown seedlings; also in or about 1885, Soltwedel, in Java, isolated the fertile seed of a wild variety *Saccharum Spontaneum*, in 1886 he was successful with *S. glonggong*, and in the following year with the Yellow Hawaii; simultaneously Harrison and Bovell had been investigating the same field, and, by growing different varieties together, hoped to obtain cross fertilisation. The arrows of these canes were planted, and eventually seedlings similar to grass shoots were observed growing by J. B. Pilgrim; since then, chiefly owing to the labours of Harrison and Jenman in Demerara, Bovell in Barbados, Hart in Trinidad, and Perromat in Mauritius, thousands of varieties have been grown, of which some have become established on the estate scale. They include—

Demerara 74, a pale green cane with dark green leaves, arrowing profusely.

Demerara 95, a dark purple erect cane with light green narrow leaves, arrowing profusely.

The above two canes were the first grown by Harrison to attract attention and to be cultivated on the estate scale; they are not now extensively grown in the country of their origin. In Louisiana they have been very successful and their acreage is rapidly extending; 74 in particular shows distinct evidence of producing a sweet juice as an inherent property. Both have also been successful in Hawaii, where 74 has held the experimental record for tons of cane and tons of sugar per acre.

Demerara 78, a reddish-green erect cane.

Demerara 102 and 115, yellow-purple blotched, brittle, erect canes.

Demerara 109, a purplish cane covered with a white bloom; at least 1000 acres of this are in cultivation in British Guiana. (1904).

Demerara 145, a greenish-purple very stout cane of extraordinary brittleness.

Demerara 625, a yellow erect cane with light-green leaves; at the time of writing considered the most promising seedling in British Guiana. Since 1901 it has easily headed the list of varieties grown experimentally on the estate scale in British Guiana.

Barbados 147, a bright yellow, long-jointed cane, rarely arrowing and a late ripener.

Barbados 156, a yellow, semi-recumbent cane, with average length of joints.

Barbados 208, a greenish-yellow upright cane with short internodes.

Barbados 306, a bright yellow upright cane.

Barbados 376, a cane resembling the White Transparent.

Mauritius 33, a green cane of recumbent habit, moderate length and long internodes, frequently exhibiting peculiar abortive joints.

Mauritius 53, a medium sized dark purple cane.

Mauritius 80, a reddish-purple cane of stout habit.

Mauritius 131, a small deep purple cane of upright habit, extremely prolific in number of canes to a stool.

Varieties of the sugar cane can also be obtained from bud variation ; the Horne, and White and Black Tannas mentioned above are well known examples.

The principles on which new varieties of plants in general are obtained are shortly as below.

The descendants of a plant in general possess the characteristics of the parent, whether propagated by seed or by cuttings, and if the descendant differs in any remarkable way from the parent, it is termed a variety and, dependant on the method of propagation, a bud variety or a seedling variety ; variation is a rare phenomenon in general and in case the variety assumes the characteristics of the original wild variety the term atavism or reversion is applied to the phenomenon. (The cane is peculiarly subject to atavism and of the many thousand seedlings raised only a few have properties which render them suitable for cultivation.) A variety once obtained may or may not be permanent, *i.e.*, continue its characteristics to its descendants. The method adopted in practice is to sow a large amount of seed ; of the resulting plants some are found, perhaps, to be varieties ; the seed of these is again planted and probably more plants will be found proportionately in the resulting crop with the characteristics of the new variety ; this process is repeated until all the plants have uniform characteristics, after which the variety is said to be permanent ; in the case of the cane a seedling variety once obtained is propagated by cuttings and not by seed.

CHAPTER IV.

THE CULTIVATION OF THE CANE.

Although the greater part of the cane sugar yearly produced is manufactured from cane grown on land that has now been in cultivation for a number of years, and in many sugar producing countries all available land is under cultivation, in some other countries virgin land is still taken in, or old abandoned land that has fallowed for a number of years and returned to its primitive condition is again put under cultivation. In general the operations to be undertaken in putting in new land may be briefly described as under : The land is cleared of all trees and bush, the heavy wood is put on one side to be used as fuel, or, if valuable, for export, the small branches, leaves, and bushes being burnt *in situ*. Very generally all this work is done by hand and the cost, especially if heavy stones (as is often the case in volcanic countries) have to be moved, is very great ; the more modern and economical method is to employ steam power. Engines capable of use either as traction or stationary engines are employed in many countries for the purpose of hauling off the land the heavy timber and large stones ; when new districts are opened up or when new land is continually taken in such a process is almost essential.

The combustion of the vegetation on new land is from one point of view entirely wrong, for the practice robs the soil of most of the nitrogen that has been accumulating for ages past. The expense of burying the vegetable matter, the slowness of its decomposition, and the harbouring places it affords for noxious insects are the reasons for this universal practice ; in addition, the burning of the vegetable matter places in the soil a large amount of readily available plant food.

After the land has been cleared in those countries which employ land carriage, roads wide enough for carts to pass are made through the new sections, and the area divided up into convenient fields ; the land is prepared for cultivation by ploughing, either by manual,

animal, or steam power. When hand labour is employed, the soil is merely turned over by forks or shovels; in other cases the whole area is ploughed, cross-ploughed and horse hoed, and the soil properly broken up and aërated.

The land being brought into condition for planting, the fields are lined out and the cane tops planted. The rows are from 3 to 5 feet wide, and also from 3 to 5 feet apart.

In British Guiana and the Straits Settlements, which are flat alluvial countries, a somewhat more complicated procedure is necessary; the area of the new plantation being decided, three dams formed by the excavation of three trenches are thrown up. These dams are known as the navigation or middle walk, sideline or drainage, and back dams, and they enclose the piece of land which is to be put into cultivation; more frequently, however, a double section is formed with two side line dams and a back dam as empoldering dams, a navigation dam running in the centre of the two half sections, and serving equally for both. In *Figs. 14* and *15* are given plans of the arrangements of field customary in British Guiana; (*a*) is the navigation dam formed by the excavation of the navigation trench (*b*); the navigation trench continues up to the factory, and is used for the transport of cane and produce, and also to supply water for irrigation and other purposes. This canal is connected with a river, creek or lake; or where this is impossible, a large canal capable of supplying a batch of estates carries water from a river. Many estates have pumping stations situated on a river, so they are nearly independent of drought; on other estates a drought may cause the level of water in the river or creek to fall so much that it is necessary to take sea water into the trenches. At (*e*) are shown cross canals communicating with the navigation trench, and terminating about 20 to 25 feet from the side line or drainage canal (*c*); the cross canals are used for the purpose of bringing the punts or barges used for transport within access of the canes; the main drainage canal runs out to the sea or river. Drainage is either forced or natural; in the former case centrifugal or sluice wheel pumps are employed, the first named being by far the most economical; in the latter case the side line discharges at low tide into the sea or river. Between the cross canals lie the fields, usually of area 10 to 20 acres, the distance from cross canal to cross canal being about 500 feet. In Demerara two kinds of fields are distinguished:—Dutch fields, *Fig. 14*, and English fields, *Fig. 15*; in the Dutch form the fields

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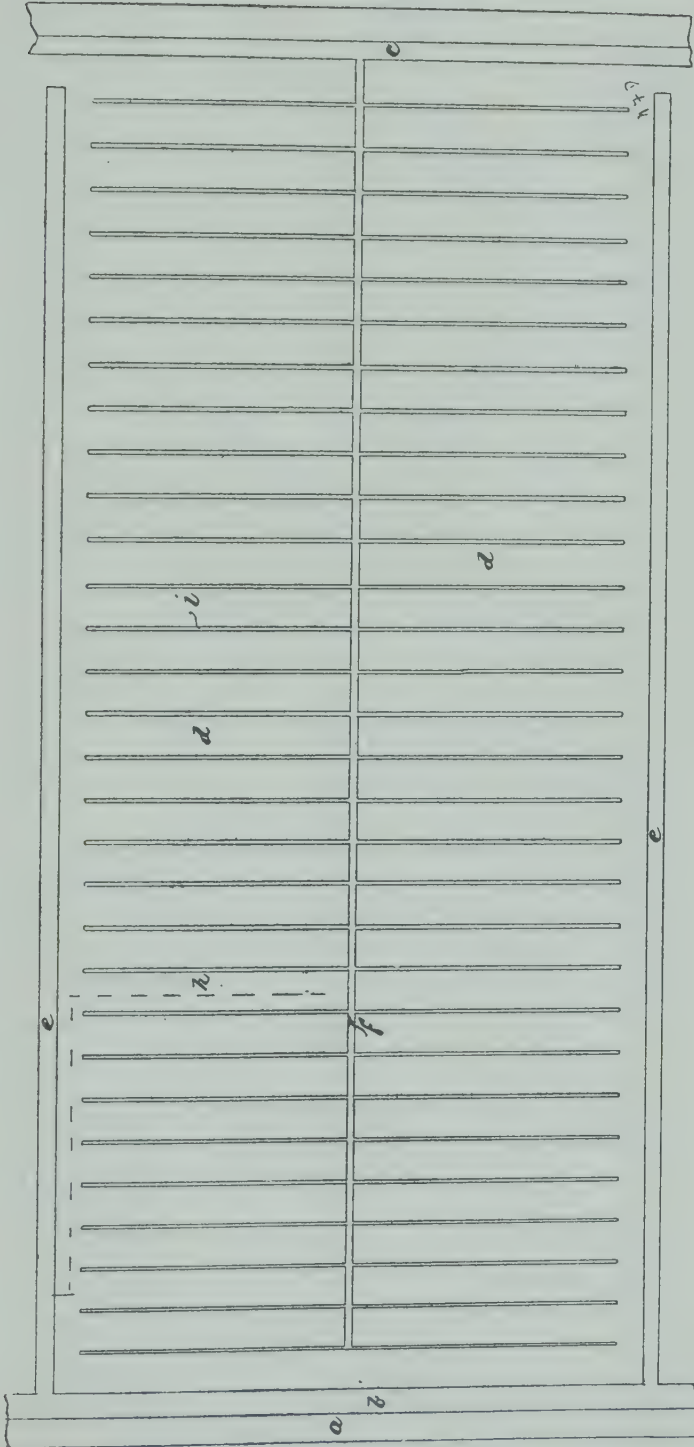


FIG. 14.

are divided into beds 35 feet wide, running parallel to the navigation trench; running down the centre of each field is the drain (*f*) known as a *tracker* or *four-foot*, which communicates with the main drainage trench; between each bed are small drains (*i*), which discharge into the four-foot. In the English fields the beds (*d*) run at right angles to the navigation trench. There is usually one bed (*g*), called the dam bed, running parallel. In front of the dam bed is a cross tracker (*h*), and between the beds are the small drains (*i*). Through the centre of the field runs, as before, the four-foot (*f*). The drains (*i*) discharge both into the cross tracker, and thence by (*f*) into the main drainage trench, and also directly into the main drainage trench; very often a centre cross tracker is also provided. The dam, called the back dam, is not shown in the sketches. It is the last dam on the estate, and serves to keep out Savannah water.

Approximate dimensions customary in Demerara are: Navigation trench, 16 ft.—20 ft. top; 12 ft.—16 ft. bottom; 4 ft.—5 ft. deep. Cross canals, 12 ft. top; 9 ft. bottom; 4 ft.—5 ft. deep. Small drains, 2 ft.—3 ft. top; 1½ ft.—2 ft. bottom; 3 ft. deep. Larger drains (trackers), 5 ft. top; 3 ft. bottom; 4 ft. deep.

The expense of clearing land, digging trenches and drains, is very considerable. From start to finish an expenditure of £12 per acre is a high figure, a fair average being £8. The expense will vary, of course, with the nature of the bush, the character of the soil, and the local price of labour.

The agricultural operations practised after land has been brought into cultivation may be briefly described. The grass and weeds are cut down and placed in banks between the rows in which the canes are to be planted. The grass, &c., is often burned off. In about a month after the canes are planted, if rains have fallen, the consequent crop of weeds is cut down, a process repeated when necessary, usually in from one to two months. By this time the young cane will have grown to a height of about two feet, and it is now given a slight moulding, *i.e.*, earthed up; after this the banks are forked and the earth well broken up. At the end of the fifth month a third weeding is done and dead leaves removed from the cane so as to give free access to light and air. After another three months, if necessary, another weeding is done and the trash again removed. A short time before the canes are cut a final removal of trash is made, the canes being harvested when about a year old. The operations for ratoon crops are precisely similar, except that immediately after

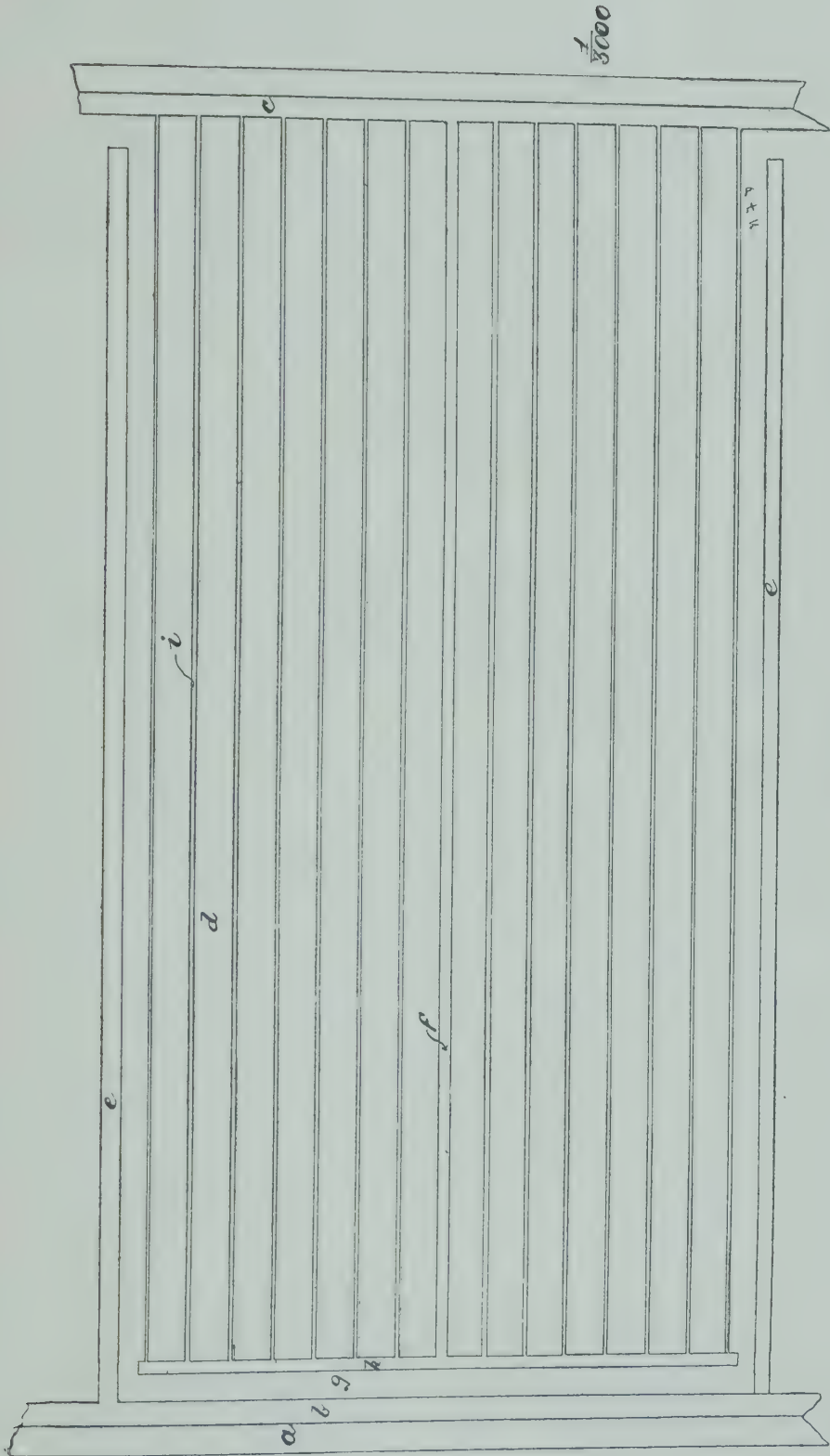


FIG. 15.

cutting the canes are relieved, *i.e.*, the trash is removed from the stumps and placed on the banks parallel to the row; the object of this is, of course, to allow light and air to penetrate to the young ratoons.

The operations described above are carried out with practically no variation in all cane growing countries. In the East, however, it is customary to earth up the canes to a much greater extent than elsewhere. The object of this is twofold; firstly, the process tends to force a great root development; and, secondly, the cane is kept more upright, when a freer access of light and air results, giving very possibly a sweeter and richer cane.

Although in many countries all the cultivation of the cane is done by hand, there is no obstacle (except in flat alluvial countries which require open drains) to the use of ploughs and cultivators.

It is in Louisiana or in places where American influence is felt that mechanical tillage has been most largely developed. In such places the absence of a large supply of cheap labour is an additional incentive to economy of labour, apart from the increased crops due to mechanical tillage. Stubbs thus describes the method of cultivation in use at Audubon Park:—"The land is broken flush with a large plough, pulverised with a harrow, and bedded with two-horse ploughs. The rows are opened with a double-mould board plough, cane planted and covered, and middles broken out with the double-mould board plough. The quarter drains are opened six inches below the middle of the rows and the ditches are cleaned. At the proper time the cane is off-barred with the two-horse ploughs, scraped with hoes, and when large enough is fertilised by scattering the mixture across the open furrows and narrow ridge of cane. The dirt is returned as soon as fertiliser is applied, the middles broken out deep and clean, and the turn ploughs sent to the barn to remain until the next season. The disc cultivator, with the three small discs on either side, is used for throwing dirt to the cane at the first working, and the middle or diamond cultivator for breaking out the middles. In the second and third cultivations two middle discs replace the three used in the first, and are set at such an angle as to throw the desired amount of dirt to the cane, and are followed each time by the middle cultivator, thus completing the work with the two implements. At "lay-by," the large or "lay-by" discs are used, followed by the middle cultivator with its two front shovels removed. By proper adjustment of the two instruments, ridges of any desired height can be made and the cane properly laid by."

Stubbs gives the area of land that can be worked by the cultivator and four strong mules as from four to ten acres per day, with ploughs from two to three acres only. The advantages of mechanical over hand cultivation do not require mention.

In Louisiana ratoon cane is cultivated with two special instruments, one called the "Stubble Shaver" and the other the "Stubble Digger." The Shaver is a horizontal rotary knife revolving when the carriage of which it forms a part is drawn along, and is used to cut down stumps flush with the ground. The essential part of a stubble digger is a shaft on which are fitted blades arranged along a helix. The carriage being drawn between the rows of ratoon cane breaks up and pulverises the soil, and according to Stubbs is capable of working 10 to 14 acres per day. Another mechanical implement largely used in Louisiana is the disc plough used to bury the pea vines grown as a fertilising intermediate crop.

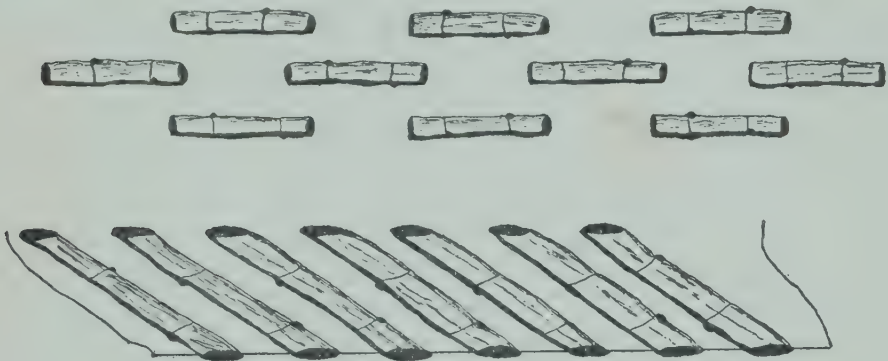


FIG. 16.

The methods of planting cane vary considerably. In general a furrow is dug or otherwise formed with the plough along the cane bed in a direction at right angles to the drains, and the cane tops buried to a depth of about six inches in the furrow so that they form an almost continuous row. The tops are pushed into the soil in a slanting direction, the upper end being allowed to project slightly above the surface of the ground; occasionally tops are planted in what is called diamond fashion, a method understood on referring to *Fig. 16*.

In some districts—notably Réunion, Mauritius, Barbados—instead of planting in furrows, the cane tops are planted in holes; the holes are from fifteen to eighteen inches long, by eight to twelve inches deep, and by eight to twelve inches wide; in an acre there are usually reckoned three thousand of such holes. A drill hole nearly

perpendicular is made in the hole into which the top is pressed, the top of the plant being left just visible; very frequently farmyard manure is placed in the hole. This method of planting is sometimes referred to as the Reynoso system.

The cane rows themselves are from three to five feet wide; in Cuba, according to Reynoso, the standard width is 1.70 metre ($\approx$ 5 feet 6 inches), the rows being the same distance apart. Bonâme gives the average width of the cane row in Guadeloupe as 1.30 to 1.50 metre ($\approx$ 4 feet 2 inches to 4 feet 9 inches.) The most economical width of row was the subject of an inquiry at Audubon Park, where it was found that the narrower the row the greater was the purity of the juice and the yield of cane, but that in very narrow rows the increased yield of cane was barely sufficient to pay for the extra amount of cane required to plant up a field with narrow rows. Stubbs suggests that that width of row which best admits of proper cultivation should be selected, and following on this argument at Audubon Park five foot rows have been adopted.

The part of the cane that is planted as seed is almost invariably the white top, but in Cuba and also to some extent in Louisiana the whole cane is used. The upper portion of the cane is less valuable as regards sugar contents than the lower parts, and in addition contains a larger proportion of nitrogen and ash, which will go to afford food for the young plant. Experiments made at Audubon Park show that there is no deterioration in the cane when the tops are continuously used as seed.

The period to which canes are allowed to ratoon varies in different countries; in Java plant cane alone is legal; in Louisiana plant and first ratoons are grown; in Mauritius the general custom is to grow up to third ratoons; in Cuba, the West Indies, and British Guiana fifth ratoons are not uncommon, and a very much longer ratooning is not infrequent.

The yield of cane to an acre is, of course, dependent on climate, soil, and season; the maximum returns are obtained on the irrigated fertile volcanic soils of Hawaii, where over a hundred tons of cane have been harvested to the acre; returns but little less are known in Peru, and virgin soils in Demerara in good seasons give from sixty to seventy tons of cane. In Mauritius an average of thirty-five tons to the acre from plant cane, with a general average of twenty-five tons over the whole rotation of four crops is very satisfactory.



FIG. 7.
STRIPED
TANNA.

2
3
SIZE

Probably the average return over all cane-growing districts is nearer twenty than thirty tons to the acre.

The following information regarding methods used in Hawaii is taken from a paper read by Stubbs before the *Louisiana Sugar Planters' Association*. The cane rows are universally five feet wide; the land is broken by steam ploughs running three feet deep, which break and pulverize the soil very finely. After ploughing, the rows are laid off by a double-decked mould board plough, working thirty to thirty-two inches deep, and the cane planted in one continuous row of tops. As soon as the tops are planted water in a little rivulet is turned on, and the labourers come behind and hoe a little dirt over the tops. In six days cane comes up with a good stand; irrigation is continued, and after each irrigation the rows are hoed. For the last two or three months water is entirely withheld, so as to artificially ripen the cane. The following are the expenses of cultivation at Ewa, expressed per acre:—Clearing, \$5·51; steam and mule ploughing, \$14·50; ditching for irrigation, \$2·05; cutting and hauling seed, \$8·22; preparing and planting, \$19·04; fertilisers, \$41·13; stripping, \$15·25; watering, \$37·13; pumping, \$35·62; manufacturing, \$27·15; packages, \$9·77; rent, \$54·63; sundries, \$32·74; total, \$302·74. The yield was 79* tons of cane, and 10·4* tons of sugar per acre.

* Tons of 2000 lbs.

CHAPTER V.

THE IRRIGATION OF THE CANE.

Water used in irrigation is measured as a flow of so many cubic feet per second, or as so many inches of rainfall per acre, and occasionally as “miners’ inches;” the latter unit is equivalent to a flow of one-fiftieth of a cubic foot per second. One inch of rainfall per acre is equivalent to 101·5 tons of water, and a flow of one cubic foot per second per year is equivalent to a rainfall of 88 inches per 100 acres, of 147 inches per 60 acres, and of 195 inches per 45 acres. In India a flow of water of one cubic foot second is given by different authorities as capable of irrigating 100, 60, and 45 acres of sugar cane, and in Hawaii experiments have shown that the maximum yield is obtained when one cubic foot second is available for every 41·6 acres.

There is probably no crop which answers so well under favourable circumstances to irrigation as does the cane; in Hawaii the crop is now independent of rainfall, and after enormous capital expenditure unequalled results are being obtained. Irrigation is also largely practised in Java, Peru (in districts where rain never falls), Egypt, Mauritius, Cuba, and, to a limited extent, in Demerara.

The following description of Hawaiian practice is based on the reports of Dr. Maxwell:—During a period of growth of about 17 months the total water supplied to the crop averages about 100 inches. Reference to the table below will show that the young cane received less water than when more mature, but not so much less as might be thought proportionate considering the different states of young and of mature cane. The causes at work are twofold; when the cane is young the whole ground is exposed to the direct rays of the sun and to the action of winds; when the cane is older the foliage shades the ground and lessens loss due to evaporation, and to a large extent conserves water in the soil. At twelve months of age the crop actually consumes in its economy ten times as much water as a crop one month old, but owing to the causes mentioned above the apparent consumption is much less disproportionate.

It was found by experiment in Hawaii that the best results were obtained when the young cane received 0·5 inch per week; less favourable results were obtained when the water supplied was one inch per week, and when the furrows were filled with water the cane came up yellow and sickly. As the cane comes away it requires about one inch weekly up to three or four months, after which 1·5 inches are necessary until the crop is in full vigour when three inches and never more are required. These figures refer to natural and artificial supplies combined. The reports quoted above give as a general figure that 1,000 pounds of water are required per pound of sugar produced, and mention that certain plantations in Hawaii use much more water than the quantities cited with less favourable results.

TABLE GIVING WATER USED IN PRODUCTION OF A CANE CROP.

Period of Application.	Monthly Rainfall. Inches.	Irrigation Water Monthly. Inches.
July	0·94	4·0
August	1·58	4·0
September	0·88	4·0
October	1·75	3·0
November	1·32	3·0
December	1·80	2·0
January	1·00	4·0
February	3·73	6·0
March	3·98	3·0
April	0·85	4·0
May	2·01	4·0
June	0·88	7·0
July	0·17	7·0
August	1·90	9·0
September	0·75	8·0
October	2·92	6·0
November	0·47	3·0
	26·99	76·00

The following figures taken from the same report contain much information regarding irrigation in Hawaii.

GALLONS OF WATER USED BY THE CROP PER ACRE.

Crop.	Volume of the Rainfall per Acre. Gallons.	Volume of Irri- gation per Acre. Gallons.	Total Water Received per Acre. Gallons.
1897-98	1,260,150	1,273,700	2,533,850
1898-99	728,990	2,059,600	2,788,590

These figures refer to a seventeen months' crop.

TOTAL CONSUMPTION OF WATER PER LB. SUGAR PRODUCED.

Crop.	Weight of Water used per Acre. Lbs.	Weight of Sugar produced per Acre. Lbs.	Water used per lb. of Sugar. Lbs.
1897-98	25,338,500	24,775	1,023
1898-99	27,885,900	29,059	959

The cost of irrigation in Hawaii is enormous; Stubbs quotes it as being \$73.75 per acre, of which \$35.62 were for pumping, and \$37.13 were for labour.

The method by which cane fields are irrigated in Demerara will be readily understood on referring to *Figs. 14 and 15*. A drain indicated by the dotted line (*g*) is dug parallel to the cross canal (*c*), and connected to it by short cuts. Down the centre of the beds irrigation drains (*h*), fifteen inches wide by nine inches deep, are dug, along which the water runs into the main drain (*f*), and thence to the main drainage trench (*c*).

In the fields described as English fields, when irrigation is necessary the main drainage trench is dammed at the proper points, and cuts made in the navigation trench so that the whole field or fields are swamped,

Irrigation is largely practised in Cuba, and, according to Reynoso, the greater part of the plantations require at least every ten days an irrigation corresponding to 1,000 cubic metres of water per hectare; turned into English units this is equivalent to 40 tons per acre per day, and to a rainfall of 150 inches per annum.

In Egypt, according to Ronna, the cane is watered as soon as it is placed in the furrow in the month of February; other irrigations follow every ten days till the end of August. From this time up to the end of October every fifteen or twenty days, after which irrigation is stopped. The water required at each irrigation is, according to Tiemann (*Int. Sugar Journal*, No. 50), 1,000 cubic metres per hectare.

In Peru cane is entirely dependent upon irrigation, the melted snow of the Andes being the source of water. The arrangement of the ditches generally followed is shown in *Fig. 17*. The *Regadora*, or main canal, leads across the higher part of the field; from this, by means of a temporary opening, water is brought to the *cavesera* and is allowed to flow out and run over the *cintas* or beds of five rows. The fields are all on the slope, and water is never pumped back, but is allowed to flow on to fields at a lower level. Where water is scarce the fields are arranged as in *Fig. 18*; *a a* are dividing ridges made with a hoe, and cause the water to run in an zigzag fashion over the field. At planting, fields are irrigated every five to eight days, and after establishment, monthly, water being cut off three months before harvest. The water supplied is not abundant, seldom more than equivalent to a rainfall of 20 inches per annum; but copious dews and heavy mists are frequent, and the perfect control of water permits crops being grown with less water than if the canes were supplied with a natural rainfall falling intermittently in varying quantities.

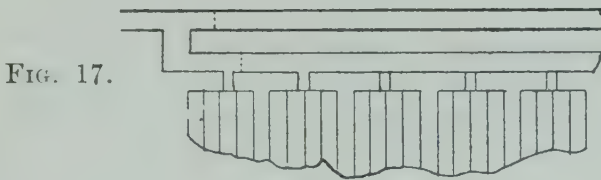


FIG. 17.

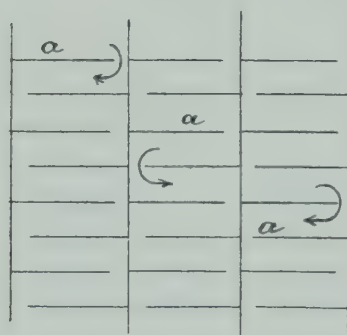


FIG. 18.

In Mauritius, where the rainfall is extremely local, some estates are entirely, and others partly, dependent on irrigation. A sketch of the system usually adopted to water fields is given in *Fig. 19*; *a a* is the main canal, sometimes built of stone and sometimes formed in the ground; *b b* are channels formed in the field down which the supply from *a a* is turned; *c c* are the cane rows along which the water is deflected by temporarily damming the channel *b b*. After one strip of the field has been irrigated, say, the one on the right (*Fig. 19*), the

water from *a a* is turned into the second channel *b b*, and a second strip watered, and so on. This method of cutting a field up into narrow strips effects great economy of water, for the latter has to traverse the whole strip to reach the side remote from *b b*, and in doing so is continually soaking into the parts nearer *b b*, and draining away. If the strip be wide and the supply of water small, the latter may not be powerful enough to travel right across the strip, so that the field cannot be completely irrigated. In Mauritius the strips are usually about 60 feet wide. The Reynoso system of planting is ill adapted for irrigation, especially with very young cane, for the water in passing down a row must fill up the holes, and as these are usually 6 inches deep by 4 inches wide, very large amounts of water, much more than required for the economy of the canes, are consumed. From observations made by the writer, an irrigation of young cane planted in holes in Mauritius takes 3.86 inches of water per

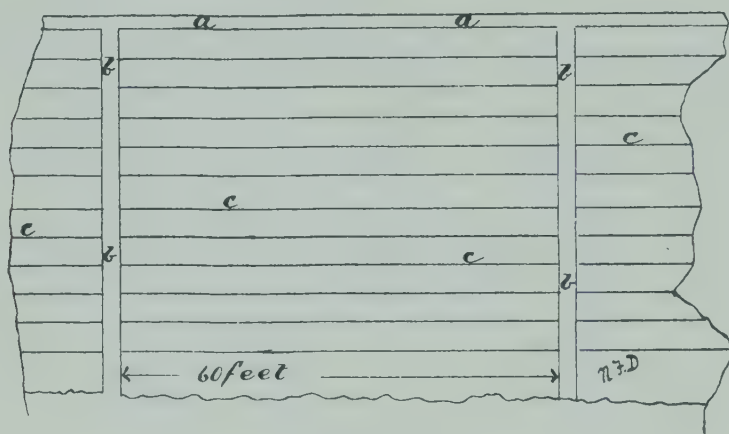


FIG. 19.

acre, calculated over the whole acreage. This is equivalent to twice that amount if calculated over the portion that actually receives the water. With narrower or shallower holes the same amount of water would have irrigated a much greater area with equally good results. The same effect is obtained by planting in furrows. In Hawaii, at each irrigation of young cane a very small furrow is formed along the row, down which the water is allowed to flow in an extremely small trickle, the maximum benefit of the water being thus obtained. Immediately after the water has flowed down the row, earth is hoed over the furrow to prevent loss of water by evaporation.

In many parts of the world where irrigation schemes, not necessarily connected with the cane, have been adopted, irrigation

has only succeeded in doing harm. Such instances have occurred in India and California. These soils contain large amounts of alkalies, which, after each irrigation, are washed down to the subsoil. Dry weather following on an irrigation, water rises to the surface, carrying in solution the alkali washed down, reinforced by that brought in with the irrigation water and that absorbed from the subsoil. In cases such as the above, irrigation must be supplemented by a complete system of subsoil drainage.

CHAPTER VI.

THE MANURING OF THE CANE.

The cane in common with other economic plants has received extensive manurial trials; amongst the most valuable published results are those quoted below.

Scard, as the result of an extended series of experiments on the Colonial Company's Estates in British Guiana, concluded:—

1. That lime used by itself gave a small pecuniary gain.
2. That lime associated with manures gives an increase sufficient to pay for itself only when used with larger (2 cwt.) quantities of soluble nitrogen, such as sulphate of ammonia.
3. That of nitrogenous manures, sulphate of ammonia at the rate of 2 cwt. per acre, gives the best results.
4. That ground mineral phosphate appears to give an increased yield compared with superphosphate.
5. That guanos, especially in conjunction with lime fall far short of ammonia in beneficial effect.
6. That an increase of phosphoric acid over the minimum employed (168lbs. per acre) fails to give satisfactory pecuniary results.
7. That neither lime nor manures produce any perceptible difference in the purity of the juice but only affect the weight of cane.

Harrison and Bovell in a series of experiments carried out between 1885-1889 at Dodd's Reformatory in Barbados came to the general conclusions detailed below; a full account of their reports will be found in the *Sugar Cane* for the years mentioned and is well worth close study. They found—

1. The addition of readily available nitrogen to mineral manures produces a large increase in the weights of cane grown, but excessive dressing (over 3 cwt. sulphate of ammonia per acre) may cause a marked decrease in the richness and purity of the juice.
2. Under certain climatic conditions, manuring with nitrogen in form of slowly decomposing organic matter may, if applied before or soon after the planting of the canes, produce excellent results.

Applications of such slow acting manures in June or July at the period of the sugar cane's most active growth are unadvisable, and may result in considerable loss.

3. Upon the soil, and under the climatic conditions existing at Dodds' during the years 1885 to 1889, both inclusive, nitrate of soda was markedly inferior to sulphate of ammonia as a source of nitrogen for sugar cane.

4. The profitable employment of purely nitrogenous manures depends largely upon the state of the soil. If the soil is in good heart, such applications may realize heavy returns, if poor such manurings will result in heavy loss.

5. For the maximum return of sugar cane by manuring, phosphates must be present in the manures used.

6. If such phosphates are applied in the form of superphosphate of lime, great care must be exercised in their use and application, as whilst light dressings of superphosphate capable of supplying 75lbs. or 80lbs. per acre of "soluble phosphate" (equivalent to from 16 to 18 per cent. of "soluble phosphates" in commercial sugar cane manures when applied at the rate of one ton to five acres), may produce large increases in the weights of canes, &c., heavier dressings do not produce corresponding increases, and excessive ones may even reduce the produce below that obtained when manuring with nitrogen and potash only.

7. The use of insoluble phosphates such as precipitated and mineral phosphates is not advisable during the period of the cane's active growth, but may produce excellent results when applied to the soil at an early period, in a very fine state of sub-division in large quantities, and uniformly mixed with it. To obtain, however, equally profitable results with these phosphates, as with moderate applications of superphosphates, it is absolutely necessary that they be purchasable at far lower prices than they can be at present obtained in Barbados.

8. The addition of potash to manurings of phosphates and nitrogen produces in all soils at all deficient in available potash large increases in the yield of cane and of available sugar in the juice per acre.

9. The most advantageous time for the application of potash-containing manures appears to be at the earliest stages of the plants' growth, and pecuniarily the use at this period of so-called early cane or potassic manures is far preferable to that of even the highest quality of manures which were formerly used.

10. The presence of an excess of potash in the manures does not injuriously affect the purity of the juice, either by increasing the glucose or appreciably the amount of potash salts contained in it.

11. No definite information has been obtained with regard to the influence of the mineral constituents of the sugar cane manures upon the saccharine richness of the canes; although, in the great majority of cases, canes receiving potassic manures have been somewhat richer in sugar than those otherwise manured. It appears, therefore, probable that increased saccharine richness must be sought in the cultivation of varieties, the careful selection of tops for planting from healthy and vigorous canes (by this selection, whilst the saccharine strength of best canes of a variety would not be increased, the average might be greatly raised), and possibly by the seminal reproduction of carefully selected canes and varieties.

In other of their reports Harrison and Bovell state that increased applications of sulphate of ammonia did not pay for the increased expenditure, that farmyard manure gave the biggest crop and also the biggest loss due to expenses in application, and that the most economical manure was Ohlendorff's early cane manure and dissolved Peruvian guano. They recommended manuring the young cane with suitable manure, such canes standing a subsequent drought better, and that afterwards phosphates and potash should be applied, the latter only if not applied with earlier manurings, and that the manures should not be applied in one but in two or three dressings.

Harrison in a presidential address to the *Royal Agricultural Society of British Guiana, 1897*, concludes as a resumé of work on cane manuring:—

1. That the weight of cane is governed by the amount of readily available nitrogen either naturally present or added as manure.

2. When applied in quantities containing not more than 40 to 50lbs. nitrogen per acre, sulphate of ammonia and nitrate of soda are equally effective manures on the majority of soils, but that when the unit of nitrogen is of equal money value it is more economical to supply the former. Dried blood and similar organic manures in which the nitrogen only slowly becomes available are distinctly inferior sources.

3. Under ordinary conditions of soil and climate and the usual range of prices for sugar, it is not advisable to supply more than 2 cwt. of sulphate of ammonia or $2\frac{3}{4}$ cwt. of nitrate of soda per acre.

4. If circumstances arise in which it is desirable to obtain the maximum yield per acre by the application of more than 50lbs. nitrogen per acre, sulphate of ammonia should always be used.

5. Practically on all soils manurings with nitrogen require to be supplemented by phosphoric acid. The most effective form appears to be superphosphate of lime and slag phosphate meal. Mineral phosphates are of distinctly lower value and are not effective unless applied in quantities far exceeding in value those required for either superphosphate or slag phosphate meal; as a rule phosphates should only be applied to plant cane, their action on ratoons being limited.

6. On some soils the application of potash salts in quantities from 60 to 160lbs. sulphate of potash per acre results in greatly increasing the effectiveness of nitrogenous manuring; soils containing less than .01% potash soluble in 1% citric acid, will as a rule respond favourably to this treatment, while those containing between .01% and .02% may or may not be favourably affected.

A series of experiments made by Bonâme at the Station Agronomique in Mauritius gave the results detailed below:—

Manure.	Plant Cane.	Return in Tons of Cane per acre.		Mean per Year.
		First Ratoons.	Second Ratoons.	
a, m, q, u	51.400	35.710	26.690	39.600
b, m, q, u	61.100	31.460	27.040	41.500
c, m, q, u	60.890	37.800	26.480	41.729
d, e, f, m, q, u	61.300	36.000	25.770	41.020
g, h, i, n, r, u	54.210	34.790	25.820	39.030
j, k, l, o, s, w	48.360	30.530	23.030	33.940
Nothing	42.680	20.090	14.330	25.630
d, e, f, m, q	31.720	18.000	10.910	20.210
d, e, f, u	29.510	15.430	11.130	18.690
m, q, u	35.660	21.820	13.610	23.530
d, e, f, p, u	64.610	37.040	29.900	43.850
d, e, f, t, u	64.680	39.760	31.790	45.410
d, e, f, r, u	62.610	39.980	30.920	44.500
d, e, f, m, q, u	58.100	39.350	30.410	42.950
d, e, f, m, q, v	57.400	38.080	31.530	42.330
d, e, f, p, q, v	52.700	36.560	29.080	37.440
d, e, x, m, q, u	46.100	34.620	24.360	35.020
m, q, u	39.450	28.370	20.729	29.510
d, e, f, u	27.670	20.400	13.290	20.450
d, e, f, m, q	21.200	14.310	6.880	14.130

a, 30 kilos nitrogen as dried blood, b as sulphate of ammonia, c as nitrate of soda
 d, 10 " " " " e " " f " "
 g, 13·3 " " " " h " " i " "
 j, 6·6 " " " " k " " l " "
 m 20, n 6, o 13·3, p 40 kilos soluble phosphates; q 20, r 25·6, s 13·3 kilos
 in soluble phosphate; t 40 kilos citrate soluble phosphates; u 30, v 40, w 20
 kilos potash; x 20 kilos nitrogen as nitrate of soda.

In general in estimating the manurial requirements of a crop it is customary to estimate by means of analysis of the plant what mineral constituents and nitrogen are removed yearly from the soil; in this way the agricultural chemist is able to say what manures and what quantities of them are necessary for the growth of the crop, provided that analysis of the soil shows that a supply of available plant food is not present in sufficient quantity. In the case of the sugar cane this argument cannot be pushed too far, owing to the great variation presented in the quantity and composition of the ash of the cane. This great variation is well shown in the adjoining analyses made by the late Dr. Stenhouse where the percentage of phosphoric acid varies from 2·90% to 13·04%, the lime from 2·34% to 14·36%, the potash from 10·09% to 39·78%; analyses of the ash of the sugar cane made by Bonâme, in Guadeloupe, show a similar variation. Different varieties of the cane, too, seem to absorb a very different amount of plant food, even when growing on the same soil. This point is well shown in figures published by the Hawaii Experiment Station. In 1900 the Lahaina cane grown there produced 4·48 lbs. sugar per pound of mineral matter taken from the soil, a variety known as Moore's Purple only producing 1·44 lbs. sugar; other varieties were intermediate between these extremes.

The amount of nitrogen contained in a crop of cane is also subject to considerable variation; experiments made by R. Glenk, and quoted in Stubbs' *Field and Laboratory Experiments for Ten Years* give the whole crop of the Purple Louisiana cane as containing ·133% nitrogen, the Striped Louisiana only containing ·106%. Bonâme estimates the cane itself to contain ·0415% nitrogen, and the leaves ·1532%, and the writer found a crop of 50,000 tons of cane as they entered the factory to contain ·045% nitrogen.

This variation in composition of ash is probably not so much due to inherent properties of different varieties as to composition of the soil upon which the cane is grown, particularly with reference to the available plant food, and no experiments seem to have been made on

	TRINIDAD.				BERBICE.			DEMERARA.	GRENADA.	JAMAICA.		
	1.	2.	3.	4.	5.	6.	7.			10.	11.	12.
Silica	45.97	42.90	46.46	41.37	46.48	50.00	45.13	17.64	26.38	52.30	48.73	54.59
Phosphoric acid	3.76	7.99	8.23	4.59	8.16	6.56	4.88	7.37	6.20	13.04	2.90	8.00
Sulphuric acid	6.66	10.94	4.65	10.93	7.52	6.40	7.74	7.97	6.08	3.31	5.35	1.94
Lime.. . . .	9.16	13.20	8.91	9.11	5.78	5.09	4.49	2.34	5.87	10.64	11.62	14.36
Magnesia.. . . .	3.66	9.88	4.50	6.92	15.61	13.01	11.90	3.93	5.48	5.63	5.61	5.30
Potash	25.50	12.01	10.63	15.99	11.93	13.69	16.97	32.93	13.21	10.09	7.46	11.14
Soda	..	1.39	..	..	.57	1.33	1.64	..	..	.80	..	..
Chloride of potash.. . .	3.29	..	7.41	8.96	..	..	..	10.70	11.14	..	16.06	.84
Chloride of soda	2.02	1.62	9.21	2.13	3.95	3.92	7.25	17.20	7.64	4.29	2.27	3.83

Nos. 1—7 and 10—12 ripe canes with leaves; No. 8, no leaves; No. 9, few leaves.

this point, although it would be a matter of great value and interest to know what composition of ash is given by a cane growing under the most favourable soil conditions.

The analyses that have been published afford, however, considerable information; an ash, such as No. 8, quoted above, denotes a superabundance of potash and a deficiency of lime in the soil, with a reasonable amount of phosphoric acid; in general, it might be assumed that the ash of the cane should contain not less than 10% of either lime, potash or phosphoric acid, and if, on analysis, a lower figure is found, the necessity for manuring with the deficient constituents is perhaps indicated.

The amount of ash contained in the cane is also very variable. Bonâme found a crop of cane to contain .35% of ash. Glenk (*loc. cit.*) found .22% and the writer found a crop as they reached the factory to contain as much as .77% and Harrison (*Sugar Cane*, April, 1887) estimates stripped cane to contain .45% ash. In addition to the difficulties mentioned above in estimating the amount of mineral matter removed by a crop of cane the weight of cane grown per acre varies; twenty tons per acre is a low return which may rise to as much as eighty or even one hundred in exceptionally favoured districts. As a standard to estimate the amount of plant food removed by a crop of cane let the return be estimated at forty tons per acre of clean cane and let this cane contain 0.5% ash, the ash containing 10% of potash, lime and phosphoric acid. There will then be removed per acre 45 lbs. of each constituent; this amount of potash will be contained in 350 to 400 lbs. kainit, or in 100 to 110 lbs. sulphate of potash, and the phosphoric acid in 250 and 300 lbs. basic slag, or 130 to 180 lbs. superphosphate, or in 60 to 80 lbs. double superphosphate or precipitated phosphate. Now suppose the ash of a crop of cane to contain only 2% phosphoric acid; the natural inference is that the amount of phosphates available in the soil is insufficient for the plants' needs and to make good this deficiency phosphates must be supplied artificially.

Harrison (*loc. cit.*), estimating the crop of cane at 25 tons stripped cane and 5 tons tops per acre, estimates the unavoidable losses per acre as 44 lbs. nitrogen, 44 lbs. potash and 25 lbs. potash; in this estimate the megass, ashes and filter cake are supposed to be returned to the soil and allowance is made for the constituents which become insoluble.

The above estimate treated of canes only; the growing crop also produces large quantities of leaves which also require mineral matter; the proportion between leaves and stalks varies very much with different varieties of cane; in general however it may be taken as roughly correct that the leaves contain as much mineral matter as the stalks. If the leaves are systematically returned to the soil no impoverishment on this score is to be feared, but as indicating, the necessity for a larger supply of available plant food, estimates made on canes alone will be much too small.

Again a plant absorbs food only when the soil is moist and hence its period of growth is limited by the rainfall unless independent of weather by means of irrigation schemes; to obtain the maximum return, it is then evident that an excess of plant food over and above that actually used by the plant must be present, so that during the periods of growth the plant has full scope to practise its economy. This is necessary for a second reason, as the roots of the cane do not come into contact with every particle of soil. With all these factors entering into the equation of plant growth it is impossible to say on first principles only what amount of plant food should be present in the soil, or what amount of manures should be applied so as to obtain the best results, and the agricultural chemist has to be largely guided by actual experiments, such as those already detailed above. One point in connection with such experiments should be mentioned, and that is their dependence on the rainfall. For example, one series of experiments shows that with a certain rainfall the plant could economically absorb 75lbs. of phosphates, and that an application of 150lbs. gave no better results. Let the rainfall over the period be 50 inches, then the result of the experiment would read that with a rainfall of 50 inches the crop could absorb 75lbs. phosphates per acre; but if the water supplied to the crop either as rainfall or irrigation had been greater, the plant might have been able to have absorbed, say, 100lbs. phosphates, and have given a much greater return.

The proportion of plant food removed by the leaves and by the stalks is a point of considerable interest. Experiments have been made in this connection by Bonâme, in Guadeloupe, and at Audubon Park in Louisiana. Of four very complete series made by Bonâme, a quite considerable variation in the distribution of plant food through the different parts of the cane is shown. In two instances where

the leaves weighed 34% of the entire crop, they contained about two-thirds of the nitrogen, half the phosphoric acid, and over three-quarters of the potash; in a third case, where the leaves weighed 18% of the crop, they contained two-fifths of the nitrogen, phosphoric acid, and lime, and half the potash; while in a fourth instance, where they weighed 14% of the crop, they contained one-third of the nitrogen and phosphoric acid, two-fifths of the lime, and over half the potash.

The results obtained by R. Glenk, and summarised in Stubbs' "*Field and Laboratory Experiments for Ten Years*," are summarised in the table below:—

MINERAL MATTER REMOVED PER TON OF CANE AND RETURNED TO
THE SOIL BY THE ROOTS, LEAVES, TOPS, WHEN TRASH IS
NOT BURNED. Figures in pounds.

Purple Cane.

	Nitrogen.	Phosphoric Acid.	Potash.	Lime.	Mineral Matters.
Total removed by crop	2.98	1.63	2.52	2.54	44.63
Amount removed by stalks	1.08	1.04	1.22	0.52	11.18
Amount returned to soil	1.90	0.59	1.30	2.02	33.45

Striped Cane.

	Nitrogen.	Phosphoric Acid.	Potash.	Lime.	Mineral Matters.
Total removed by crop	2.38	2.07	4.18	2.03	41.59
Amount removed by stalks	0.88	1.30	2.34	0.58	12.40
Amount returned to soil	1.50	0.77	1.84	1.45	29.19

The preceding pages referred chiefly to the mineral matters required to support a crop of cane and did not touch on the position of nitrogen; often nitrogen is applied not so much as a plant food but as a stimulant so as to obtain a vigorous young growth, it being a matter of common observance that canes which have received as young plants a liberal dressing of ammonia are able to pass through subsequent periods of drought with less damage than others. In certain cases, as in rich forest or bush virgin soils, or in soils which have been liberally green manured, nitrogenous manurings are quite



FIG. 8.
BLACK
TANNA.

2
3
SIZE

out of place; such soils which may in certain cases contain up to 1% of nitrogen hold a supply which will take years to exhaust, and if the trash be left on the soil and the factory offal be returned, the soil should retain its fertility almost indefinitely.

The amount of nitrogen contained in a crop of cane is divided between that in the stalks and that in the leaves; the figures due to Glenk quoted above show that in certain instances the leaves and tops contain quite two-thirds of the nitrogen, so that it is the non-productive part of the crop which produces most soil exhaustion; in some districts the custom obtains of burning the fields before cutting, of burning the trash left in the field after cutting, and of carting the trash to the factory for use as fuel. Now, on an average, a crop of cane of 40 tons to the acre will give 24 tons of dry straw or trash, which will contain about 50 lbs. of nitrogen. Taking the manurial value of nitrogen as 7½d. per lb. the 50 lbs. nitrogen contained in the trash per acre represents a money value of £1 11s. 3d. and per 1,000 acres of £1,562 10s. 0d. It is not only, however, by the money value of the nitrogen that the soil suffers, but the presence of the decaying trash in the soil helps to retain moisture and very materially increases the good condition of the land. On the other hand experience has shown that land from which the trash has been burned generally shows a much better spring in ratoon crops than land where the trash is buried, the ash constituents being set free and rendered available for the needs of the growing plant; again, where canes are burned before cutting, very considerable sums are saved in the labour of cane cutting; as much as five to six shillings per acre. Perhaps the most valid argument in favour of burning trash is that by so doing the harmful insects, as well as the spores of the various parasitic organisms which attack the cane, are in very great part destroyed, and finally, when trash is left on the field considerable sums are spent in '*relieving*' or removing trash from the young ratoons. Whether trash should be burned or not is a question which must be answered entirely by local considerations; in Mauritius where fuel is expensive much trash is carted to the factories, the ashes being afterwards returned to the fields.

The amount of money which is annually expended on manures on a sugar estate is very considerable; few properties spend less than than 20 or 25 shillings per acre, and this expenditure is often exceeded. Now a sugar estate sends into the market, either as sugar or rum,

only carbon, hydrogen, and oxygen, which have no manurial value; it follows that if the offal be systematically returned to the soil, the impoverishment of the land is nil. A sugar estate considered as an agricultural cycle is very different to a farm, where annually plant food is removed, such as in the sale of milk, cattle, or grain; if then the soil once be in a condition to produce heavy crops, it should remain so for many years, and should even improve with the addition of the excreta of the plantation stock. In part, however, this argument is fallacious, as the small proportion of nitrogen contained in the megass is lost, and the sugars will contain a proportion of ash and nitrogen, the more so the lower the class of sugar made; molasses, too, in some instances are sold off the estate. In order to estimate the quantity and distribution of the ash and nitrogen brought into a factory, the writer made the analyses detailed in the Tables below, for a factory working up 50,000 tons of canes; the process used in the factory was dry double crushing and simple lime defecation; no sulphur or phosphoric acid was used. In Table I. are given analyses of the ash of various products; in Table II. the total amounts entering the factory per 1,000 tons of cane; and in Table III. the distribution of the nitrogen and the constituents of the ash over all the factory products, the amount in the canes being put equal to 100. Inspection of these tables will show that on this particular estate the amount of potash in the canes was abnormally high, and that of the lime equally low, the phosphoric acid being deficient.

TABLE I.

	Juice.	Megass.	Canes.	Filter Cake.	Sugar I.	Sugar II.	Lees.	Yeast Deposit.
Ash per cent.	·67	1·00	·77	11·55	1·15	3·54	1·79	..
Lime	1·22	2·41	1·33	17·96	4·73	4·64	6·53	..
Magnesia	4·72	2·92	3·96	5·11	2·70	2·95	3·98	..
Potash	40·84	16·82	31·23	1·07	39·54	37·26	41·82	..
Soda	2·18	1·53	1·92	Trace	1·90	1·63	2·32	..
Phosphoric Acid	4·97	3·25	4·15	16·77	2·74	3·67	1·61	..
Sulphuric Acid.	15·49	6·22	11·72	1·71	22·60	23·42	20·88	..
Nitrogen*	·052	·028	·045	1·50	..	..	·101	1·96

* Per cent. on actual material.

TABLE II.

	Total Ash.	Lime.	Mag- nesia.	Potash.	Soda.	Phos- phoric Acid.	Sul- phuric Acid.	Nitro- gen.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Canes	17300	295	690	5380	330	740	2040	1010
Used in Manufacture ..	..	850	..	..	..	..	590	80
Juice	10270	125	480	4190	220	510	1590	810
Megass	7030	170	210	1180	110	230	440	200
Filter Cake. .. .	1830	350	95	20	..	310	30	230
Sugar I.	1620	80	43	640	20	45	370	..
Sugar II.	690	30	20	250	10	25	160	..
Lees	7600	460	300	3180	180	120	1560	440
Yeast Deposit	..	..	..	..	..	..	..	195

TABLE III.

	Ash.	Lime.	Mag- nesia.	Potash.	Soda.	Phos- phoric Acid.	Sul- phuric Acid.	Nitro- gen.
Canes	100	100	100	100	100	100	100	100
Used in Manufacture ..	..	288.0	..	..	..	..	28.9	7.9
Juice	59.4	42.4	69.6	78.0	66.6	68.9	77.9	80.2
Megass.	40.6	57.6	30.4	22.0	33.3	31.1	21.5	19.8
Filter Cake. .. .	10.6	118.6	13.8	0.4	..	41.8	1.5	22.8
Sugar I.	9.3	26.0	6.2	11.9	6.1	6.1	18.1	..
Sugar II.	3.9	10.2	2.9	4.6	3.0	3.4	7.8	..
Lees	43.9	155.8	44.1	59.1	54.1	16.2	76.5	43.5
Yeast Deposit	..	..	..	..	..	..	..	19.3

The amount of plant food lost in the factory operations is that carried away in the sugars together with the nitrogen lost in the combustion of the megass; roughly speaking the sugars carry away 10% of the ash constituents contained in the canes, and 20% of the nitrogen is lost with the megass. In accordance with what has already been written, this would represent a loss only half as great when referring to the whole crop—cane and trash.

Although nearly the whole mineral and nitrogenous matters of the crop are retained in the factory bye-products, their economical return is a matter of no inconsiderable difficulty. The filter press cake, rich in nitrogen and phosphates, is in a form easily handled, and its application presents no difficulty; no loss of nitrogen need be feared if it be necessary to store the press cake over lengthy periods, as the annexed analyses show. These analyses of press cake from the same factory were made by the writer to test this point:—

	Nitrogen per cent. on dry matter.
Fresh press cake	1·173
Press cake, 12 weeks old, exposed to weather	1·184
Press cake, 100 weeks old, stored under cover	1·189
Press cake, 100 weeks old, exposed to weather	1·172

The megass ashes, rich in phosphates and potash, are also readily applied; in this material the potash is in great part soluble in water, and if exposed to rain the most valuable constituent is leached out and lost.

In the analyses given above a material is referred to under the name “yeast deposit”; by this is meant the sedimentary deposit of dead yeast cells occurring in the fermentation vats. For the particular distillery on which this estimate is based, 2·5 gallons of a thick sludge of yeast cells were produced per 100 gallons of wash; one gallon of this sludge contained 1·43 lb. solid matter and ·196 lb. nitrogen, or 13·70% on the solids. There is here a source of a concentrated nitrogenous manure which is often run to waste; the deposit might be collected and applied in its natural condition or passed through filter presses and obtained as a cake carrying 50% to 60% water and 6% to 7% nitrogen. Per 1,000 gallons of wash about 50 lbs. of such cakes would be obtained, and per 1,000 acres about 20 tons would result.

The material which offers the greatest difficulty with regard to its economical return is the lees or distillery refuse; the following methods suggest themselves:—

1. Concentration to small bulk.
2. Destructive distillation and incineration of residue, collecting the distillates and recovering the phosphates, and especially potash, in the residue.
3. Irrigation of cane fields with lees.

4. Precipitation with lime and collection of the resulting precipitated phosphates and nitrogenous matter.

5. Collection of the lees in ponds and subsequent excavation of the "lees mud" and application as manure.

The concentration of the lees to a density of 1.25 would mean an evaporation of 90% of their weight, and even if performed in an efficient multiple evaporator would entail great fuel consumption in value over and above the value of the produce obtained. The same obstacle stands in the way of the incineration of the residue, although certain beet sugar factories which work up their molasses for beet spirit treat the "Schlempe," or "vinasse" (as the lees are termed) for collection of potash residues.

Lees irrigation has been tried, and there is much to be said in favour of this method of conservation of valuable plant food. Experiments in Scotland have shown that the refuse from whisky distilleries is not, at any rate in the quantities in which it would be applied, injurious to vegetation. Such a scheme was once actually in operation in Demerara, but the distillery being burnt down and not re-erected, it was not continued.

Lees when treated with lime give a copious precipitate; it was found by direct experiment that to completely precipitate 1,000 gallons of lees, 150 lbs. of commercial lime were necessary; after treatment with lime, lees that contained originally .01040 lb. nitrogen per gallon now contained .00406 lb., so that over 60% of the nitrogenous matter was recovered in the precipitate. On filtration a sludge was obtained, in volume about 15% of the lees treated; when dry this material contained 3.82% nitrogen. To treat lees in this way would require no expensive outlay, but the method would still let the potash run to waste; per 1,000 tons of cane, 4 tons more or less of a filtered sludge carrying 50% water would be obtained, the material containing about 1.9% per cent of nitrogen.

The present method of utilising lees is to run them into a pond or blind trench which is periodically excavated and the material obtained, a soft black mud, carried to the fields; this method, while allowing of a considerable loss in drainage, is expensive owing to the bulkiness of the material. Where the estate has a large quantity of cattle and where the pen manure is systematically collected the lees can very well be absorbed by the soiled litter.

In many districts a distillery is not an adjunct of the sugar house and instead of having lees to dispose of, molasses form the refuse of the factory ; in Hawaii the final molasses are often returned to the soil in the irrigation water. Another method of utilising the molasses is to feed them to the plantation stock and to recover their manurial value in the excreta of the animals.

In those countries which employ animal traction very large numbers of cattle and mules are kept for transport purposes and large quantities of pen manure are produced annually, and it is remunerative to stall the cattle at night with sufficient litter, such as dry cane trash, to absorb their urine. In Mauritius great attention is paid to this source of manure. The method adopted is as follows.

The live stock of the estate which may number from two to three hundred are in great part kept in 'parcs' which may be from fifty to a hundred yards square ; a portion of the parc is often covered in to provide shelter in inclement weather. The whole area of the parc is covered with cane trash transported from the fields and used as bedding. During the whole year if the supply of labour is sufficient, the soiled litter is in a continual process of renewal and removal, the bedding being renewed throughout on an average of once a week ; on removal it is placed on stone platforms or in basins ten feet deep, both platforms and basins generally being about fifty feet square. The whole mass when completed is continually watered with fermented molasses and water or distillery refuse, and sometimes with dilute sulphuric acid ; the drainings collect in stone pits and are continually repumped over the heap of manure ; the object of this is to rot the manure and at the same time to fix any volatile ammonia given off. In from six to twelve months the manure is considered sufficiently rotten to place on the fields, where it is applied at the rate of from ten to twenty tons per acre to plant canes only ; generally at an age of three months, or occasionally, the cane holes are filled with the manure and the tops planted on it.

The amount of manure made per animal per year is from fifteen to twenty tons where bedding is used, and where the dry dung only is collected, from two to three tons.

It is very often the case that manure making is forced, that is to say, more straw than necessary to absorb the urine and contribute to the comfort of the animal is brought in as bedding ; the false economy of this proceeding is apparent but its practice is not uncommon.

The composition of the manure varies within considerable limits; where a reasonable amount of bedding has been used the percentage of nitrogen generally, in the writer's experience, lies between $\cdot 6\%$ and $\cdot 8\%$ falling to $\cdot 3\%$ to $\cdot 5\%$ where an excess of trash has been brought to the stables or pens; the potash and phosphoric acid do not seem to show any variation dependent on the amount of bedding used, both lying between the values $\cdot 2\%$ to $\cdot 7\%$; these figures refer to manure with from 70% to 80% of moisture.

The expense of making pen manure is very considerable; the cost varies from two to five shillings per ton, a portion of which expense would be incurred in any case; the carting and application costs about one shilling per ton, making the total outlay from four to five shillings per ton. This expense is very considerable and in general it may be said that where stock is kept on the estate it will pay to carefully conserve their excreta, but it will not pay to keep animals to make manure, or to force the production beyond its natural limits.

Although not actually manuring, the practices of rotations, green soiling, and fallows may be touched on here in their special connection with cane cultivation. Different crops have a predilection for different forms of mineral matter and thus remove from the soil very different amounts of the different constituents of plant food, so much so that the ash of a crop may consist in general of one predominant constituent; by growing continually one and the same crop on the same piece of land there is then a tendency to exhaust one particular constituent. If, however, different crops be grown in rotation an element of plant food which was removed in large quantities in one year is not absorbed to such an extent by the succeeding crop, and by the time the crop first in rotation is planted a second time a sufficiency of the particular material exhausted by this crop will have become available due to the natural process of disintegration which soils are continually undergoing. As an example of such a rotation the Norfolk system may be quoted; this is wheat, roots, barley, clover; the roots are consumers of potash, the wheat takes up phosphates, the barley absorbs silica, and the clover feeds largely on lime and magnesia. The continual growth of one crop, say roots, would result in the rapid removal of the available potash.

In sugar cane planting rotation is not by any means general; the Chinese have, however, for centuries past alternated cane with indigo. In Java a rotation of rice, indigo and cane is common, and in Louisiana the rotation is plant cane, ratoon, cow peas (*Vigna catjang*).

The absence of a rotation is, in general, a weak point in sugar cane culture; the rich fertile soils which are often met with in the tropics can for a number of years support a continuous unvaried crop, but eventually they must become barren; in certain countries, as Demerara where abundance of virgin soil awaits cultivation, proprietors can continually empolder new land and allow that which has become barren to lie fallow and after a space of time, during which by the continued disintegration of the soil plant food has become available, again plant the old abandoned land.

Fallows are of two kinds, naked and covered fallows. The former are ruinous and wasteful; in the first place the tilth is destroyed and the land gets out of condition and in bad heart; secondly, what nitrates are formed by nitrification and what nitrogen is brought into the soil by rains are carried away in drainage, there being no cultivation on the soil to take them up, and store them in an insoluble form for future crops.

Green soiling or green manuring is a practice which has been carried on for generations past. In Europe the method employed is to sow a catch crop of some quickly growing plant between the harvest of the one and the seed time of the succeeding crop; the catch crop is ploughed into the soil and acts as a green manure to the following crop. The principles of this practice are as follows. It had been known for a large number of years that leguminous crops (beans, peas, clover, etc.), although they contained large amounts of nitrogen, did not respond to nitrogenous manurings, and even frequently gave a smaller crop when manured with nitrogen than when unmanured. It was eventually established by Atwater in America, Marshall Ward in England, and Hellriegel and Wilfarth in Germany, about 1886, that leguminous plants are able to absorb nitrogen from the air. The absorption is not made directly by the plant, but by the agency of bacteria. If the roots of a leguminous plant be examined, there will be found attached to its rootlets a number of wart-like excrescences the size of a pin's head and upwards. These bodies, which are termed nodules, on being crushed and examined under the microscope, are found to consist of countless numbers of bacteria, these bacteria, living in symbiosis or commensalism with the host plant, supply it with, at any rate, a part of its nitrogen.

If then leguminous plants be sown and allowed to reach maturity, and then be ploughed into the soil, there is placed in the soil a large amount of nitrogen obtained from the air. The cultivation of such

crops in connection with cane cultivation is very largely practised in Louisiana, Mauritius, and Egypt. In Louisiana after plant cane and first ratoons have been grown the land is sown with cow peas (*Vigna catjang*), using from one to three bushels per acre; in August or September the peas are ploughed in and cane planted in October. According to Stubbs the crop of cow peas above ground is often removed for fodder for cattle, planters who do this holding that the roots supply sufficient nitrogen for the crop, but Stubbs states that when the green crop is ploughed in an average increase over plant and first ratoon cane of 7.42 tons per acre is obtained over that obtained when the green crop is removed for fodder; the amount of nitrogen afforded by a crop of cow peas is, according to Stubbs, about 100 lbs. per acre.

In Mauritius there are four crops used as green manures:—

1. The Pois d' Achéry (*Phaseolus lunatus*).
2. The Pois Muscat (*Mucuna atropurpurea*).
3. Pigeon Pea (*Cajanus indicus*).
4. Indigo sauvage (*Tephrosia candida*).

The first two are pea vines growing in dense thick matted masses. The pigeon pea is a shrub growing to a height of four or six feet; the indigo sauvage is also a shrub, but of rather less robust habit. The system generally followed is to grow cane up to third ratoons; the land is then planted with one or other of the above crops, the time during which it is rested under the leguminous crop being from one to three years, dependent on the land available. Where land sufficient for one year's rest only is available the pois muscat is generally grown; the pois d' Achéry is generally allowed to grow for two years, and the pigeon pea and indigo for three or four. All four crops are planted from seed, which is sown about 15 to 18 inches apart. Where no land can be spared to rest, one or other of the above crops is occasionally sown between the rows of cane, and after a few months' growth cut down and buried.

Amongst other plants used as green manures in tropical countries may be mentioned the earth nut (*Arachis hypogea*), the soy bean (*Soja hispida*), sun hemp (*Crotalaria pinncea*), the common tropical bean (*Dolichos lablab*), woolly pyrol (*Phaseolus Mungo*), and the indigo of commerce (*Indigofera tinctoria*).

Although the benefits of green manuring are undoubted, it must be remembered that the expenses connected with it are not small, and very possibly where virgin soil can be had in abundance it may

be more economical to continually take in new land than to renew the fertility of old; the benefits of green manuring are most pronounced on estates which have to continually plant on the same soil; such estates are found in Mauritius, Barbados, and other small islands.

Besides placing in the soil a supply of readily available nitrogen, green manuring has other advantages.

1. The advantages of a rotation are obtained.
2. The deep tap-roots of leguminous plants bring available plant food from the sub-soil to the surface soil.
3. The ill effects of a naked fallow are avoided.
4. The interposition of a crop other than cane will act as a prophylactic towards fungus diseases and attacks of insects, for if the habitat of these parasites be removed for any length of time it must result in their diminution or disappearance from lack of food.

In certain quarters, notably in Mauritius, after land has been under leguminosae for a time, it is prepared for cane cultivation again by burning off the green above-ground crop. This process would seem to destroy the very benefits to obtain which the green manure was planted. Planters who follow this system claim as good a result as when the green crop is buried, and point to the saving in expense. To obtain definite information as to this process the writer grew on small plots equal to $\frac{1}{500}$ of an acre crops of the *Phaseolus lunatus* and *Mucuna atropurpurea*. The results calculated out to an acre were as below. The crop in both cases was six months between planting and harvesting, which was done when the seeds were ripe.

			Phaseolus lunatus Kilos.	Mucuna atropurpurea Kilos.
Weight, dry matter, in green crop			1621	2522
„ „ beans			132	466
„ „ roots			123	80
Nitrogen „ in green crop .. .			30.3	54.0
„ „ roots			1.2	.7
„ „ beans			5.6	16.7
Potash „ in green crop .. .			42.0	46.5
„ „ roots			4.4	2.1
„ „ beans			1.2	9.5
Phosphoric acid in green crop			11.4	14.4
„ „ roots			1.1	.4
„ „ beans			.7	4.2

It will be seen that about 80% of the manurial value of the crop was contained in the green crop; if this is burnt off the nitrogen is lost but the potash and phosphoric acid remain in a form readily available for the coming crop of cane. The economy of burning off the green crop and losing the nitrogen is comparable with the practice of burning off trash; in any case there is obtained a large amount of mineral plant food brought up from the subsoil. The high nitrogen content of the bean straw, and the possibility of using this material as bedding for plantation stock and thus both conserving it and obtaining a pen manure rich in nitrogen, is worthy of notice.

The question of nitrification in soils may be touched on here. Nitrogen is applied as manure in three forms; as ammonia, as organic nitrogen, and as nitrates; the plant absorbs it only in the latter form. In the soil there exist three classes of organisms; one which converts organic nitrogen to ammonia, a second converting ammonia into nitrites which are oxidised by a third into nitrates; of the organisms which convert ammonia compounds into nitrites two genera are known, one genus *Nitrosomonas* existing in the old world and the other *Nitrosococcus* in the new world; the genus converting the nitrite to nitrate has received the name *Nitrobacter*.

The conditions under which nitrification best occurs are:—

1. A plentiful supply of air; hence the soil must be thoroughly broken up and tilled.
2. Absence of light.
3. Water; but not an excess, which is as harmful as a deficiency.
4. The presence of a base in the soil to neutralise the nitric acid formed which would otherwise have a toxic effect on the organisms; hence vegetable moulds and heavy clays which are deficient in this respect should be treated with applications of lime.

Conversely to the above process a denitrification process goes on, the conditions favourable to which are the opposite of those above; the process only takes place in the absence of air and hence in water logged, untilled, badly cultivated soils.

The properties and composition of the artificial manures occurring in commerce are briefly detailed below.

Nitrogenous manures: Sulphate of Ammonia.—The pure body contains 21.21% of nitrogen and as sold contains from 5% to 10% of impurities including moisture, reducing the percentage of nitrogen to 19% or 20%; ammonia is generally conceded to be superior to nitrate of soda for

sugar cane culture, but this is a point entirely dependent on climatic influences. Where heavy rainfalls are liable to occur, without doubt ammonia is the superior form as it is to a large extent retained in the soil, and is less liable to be leached out in drainage water, but where the rainfall is small and the necessary water is brought to the cane by carefully controlled irrigation schemes, conditions may be entirely reversed.

Nitrate of Soda.—The pure body contains 16·5% nitrogen and as met with in commerce is about 96% pure; this manure is extremely soluble and must be applied with great care where heavy rains are likely to fall.

Nitrate of Potash.—The pure body contains 13·8% nitrogen and 46·5% potash and carrying two elements of fertilising value is economical as regards expense of application. This material does not appear in the world's markets to any extent as a manure; it, however, finds its way to Mauritius (where it is greatly esteemed) from India, and also occurs and is used in Egypt as a cane manure.

Seed Cake Manures.—The refuse of seeds which have been crushed for oil comes on the market in large quantities as manure; the plants which contribute most largely are cotton, linseed, earthnut, castor oil and cocoa nut; following on origin the percentage of nitrogen varies generally from 3% to 8%. Samples of material analysed by the writer contained of nitrogen: earthnut, 7·42%; castor oil, 6·44%; cocoa nut, 3·22%; the potash and phosphoric acid in all cases lay between 2% and 3%. As a general rule seed cakes only compete with ammonia and nitrate in places where they are produced, the question of freight making it in general more economical to import the more highly concentrated forms of nitrogen; cottonseed cake is largely used in Louisiana where it is produced in the same districts as the cane. The nitrogen in seed cake manures is in an insoluble form and before absorption by the plant has to be converted by the micro-organisms of the soil to the form of nitrate; this conversion is very rapid and the availability is but little inferior to that of ammonia or nitrate; its absolute insolubility is an advantage in times of heavy rainfall as there is no possibility of its nitrogen being washed out of the soil.

Dried Blood as it comes on the market contains from 10% to 14% nitrogen; its action is similar to but slower than that of seed cake.

Fish Scrap is of very variable composition and is slower in action than any of the above.

Guanos.—The original deposits of guano have long been worked out but manures prepared to simulate the original Peruvian are often met with; they contain from 5% to 8% nitrogen, from 10% to 15% soluble phosphates, and from 3% to 8% potash.

Phosphate Manures: Bones.—Bones in various forms are frequently met with in commerce. They contain from 4% to 6% nitrogen and from 40% to 50% phosphate of lime; this form of manure is sold as half-inch, quarter-inch, or as bone meal or dust; it is frequently steamed to remove fat and grease. The nitrogen is of little availability and the phosphates, unless the bones are finely ground, are but slowly assimilated.

Mineral Phosphates contain from 25% to 35% phosphoric acid and 35% to 50% of lime; they are mined chiefly in Norway, Florida, Algeria, and Christmas Island; occasionally they are put on the market without previous chemical treatment but mechanically ground to a fine powder; they are very slow in action and have found no extended use.

Superphosphates.—By treatment with sulphuric acid, mineral phosphates are converted to a soluble superphosphate. When a superphosphate is applied to a soil it unites with the bases present, chiefly iron and alumina, and forms insoluble phosphates; but the phosphates being precipitated within the soil are now present in a much finer state of division than could ever be obtained in a mechanically ground phosphate and are besides distributed more uniformly through the soil; they accordingly offer a much larger surface to the roots of the plant and are much more available than mineral phosphates. Superphosphates have an acid reaction and are thus injurious to the nitrifying organisms; their application to heavy clays or vegetable moulds which do not contain a base to neutralise them is not to be recommended; they do best on soils containing large amounts of lime. Superphosphates contain generally about 20% soluble phosphoric acid. Recently a manure containing 40% to 50% phosphoric acid and known as “double superphosphate” has been put on the market; this body should be serviceable where freight is high.

Thomas Slag, Basic Cinder, and Phosphate Meal are the names given to the refuse slag from the Thomas-Gilchrist process for the manufacture of steel; the phosphoric acid exists in this material as a tetrabasic compound, a state of combination different to that in

either superphosphate or mineral phosphate. The phosphoric acid is not soluble in water but is readily so in dilute citric acid and has been shown by many field trials to present a source of phosphoric acid readily assimilable by plants; the degree of fineness to which it is ground has a large effect on its availability and it is usually sold on a guaranteed basis of fineness as well as on the percentage of phosphoric acid. The general custom is to express the fineness centesimally on parts which pass through a sieve with a mesh of 250 wires to the lineal inch; slag 80% fine means that 80% of the material will pass through this standard sieve; the percentage of phosphoric acid varies from 15% to 20%, and that of the lime from 40% to 50%, a part of which exists as free lime. This manure has been found to give the best results when used on clayey and peaty soils, in fact those soils which require an alkaline base to neutralise the nitric acid formed by the organisms of the soil (see above).

Basic Superphosphate is a patent material formed by incorporating lime with superphosphate: it has been recommended for use on soils where the application of superphosphate is contraindicated.

Reverted phosphate.—Superphosphate of lime on storage has a tendency to pass into a less soluble form known as ‘reverted phosphate’ or ‘citrate soluble phosphate’; opinions as to the value of reverted phosphate differ greatly, some authorities putting it equal to superphosphate; probably it is the better material to use on soils deficient in lime; it is manufactured and sold as precipitated phosphate, containing from 35% to 40% phosphoric acid soluble in citrate.

Potash manures: Kainit.—Kainit is a crude mixture of the sulphates and chlorides of potash, soda and magnesia, containing about 12% of potash; the raw material, as well as the refined sulphate of purity about 96%, appears on the market, and which is best to use is chiefly a question of freight.

The method of application of manures so as to obtain the maximum benefit is not always the same. Readily soluble manures as sulphate of ammonia and nitrate of soda are best applied as top dressings to be carried down by rains to the roots of the plant.

Organic forms of nitrogen which require to be acted on by micro-organisms should be incorporated in the top two or three inches of the soil as it is here that nitrification is most active; in clays, which are less permeable than loams, nitrification ceases at less depths and

consequently organic nitrogen manures applied to clays require to be worked in it at a less depth. Superphosphates are also applied as a top dressing or worked into a very slight depth, but slag phosphates, and especially mineral phosphates require to be worked into the soil; mineral phosphates are valueless unless actually brought into the sphere of action of the plant's roots. Potash although soluble, is in contact with soil rendered insoluble and retained in the soil; it must therefore be worked into the ground within the region of access of the roots; the retention of potash and phosphates by the soil is so absolute that little or no danger of loss is to be apprehended if applied to the hole or furrow before planting.

The question of the valuation of manures is a special subject of its own, and outside the scope of a work of this nature. As, however, questions connected with this subject are often put before the sugar-house chemist in the tropics, the following table of the relative values of different forms of plant food, based on that adopted by the Massachusetts Experiment Station, 1894, is given. No attempt is made to fix any definite values, as these will vary in the tropics, dependent on local conditions, on soil and climatic influences, and on the cost of freight and transport.

Nitrogen in sulphate of ammonia	100
Nitrogen in fine ground dry fish, meat, blood, bone	97.4
Nitrogen in cotton-seed cake, castor pomace, &c. . .	79.0
Nitrogen in nitrate of soda	76.3
Nitrogen in coarser ground fish, bone, &c. .. .	63.2 to 79.0
Nitrogen in hair, shoddy, waste, &c. .. .	38.4
Phosphoric acid soluble in water .. .	31.6
Phosphoric acid soluble in ammonium citrate (reverted phosphate)	30.5
Phosphoric acid in bone, tankage, &c., dependent on degree of coarseness	10.5 to 30.5
Phosphoric acid in seed cake and wood ashes	26.2
Phosphoric acid insoluble in ammonium citrate (mineral phosphates)	10.5
Potash in high-grade sulphate	26.2
Potash in high-grade chloride	23.7

The relative values of manures in the English market at the same time were very different. They are given below:—

Nitrogen in sulphate of ammonia	100
Nitrogen in nitrate of soda	112·1
Nitrogen in castor oil seed cake	133·0
Nitrogen in horn dust	118·0
Nitrogen in dried blood	110·4
Potash in sulphate	40·0
Potash in chloride	36·5
Nitrate of potash { Nitrogen	104·3
{ Potash	39·3
Phosphoric acid in superphosphate	20·9
Phosphoric acid in mineral phosphates	10·4
Phosphoric acid in basic slag	13·0



FIG. 9.
WHITE
TANNA.

3
1
SIZE

CHAPTER VII.

THE DISEASES AND ENEMIES OF THE CANE.

The enemies of the cane with which the planter has to contend may be classed as animal, insect, and fungoid. Of animal pests the one that does most damage is the rat; it attacks chiefly young cane, and at times does immense damage; it can only be kept under by systematic destruction by dogs and by laying down poisoned food. The journal *La Agricultura de Guatemala* gives the following receipt as an efficacious rat poison :—

Soft bread.	125 parts.
Grease	60 „
Crystallised nitrate of mercury	30 „

The lamentable result of the introduction of the mongoose into Jamaica as a rat destroyer is well known. As an advanced scheme for destroying rats the laying down of food infected with cultures of the organism producing the disease *Septicaemia muris* has been advocated and tried, but the success was distinctly problematical.

Of the insect pests of the cane the one which has done most harm and been most extensively studied is the moth borer; two varieties are known, the name *Diatraea saccharalis* being given to the neotropical species, the palæotropical variety being called *D. striatalis*. Other names under which they occur are *D. sacchari*, *Proceras sacchariphagus*, and *Phalaena saccharalis*; the allied genus *Chilo* also produces varieties attacking the cane, such as *C. infuscatellus* in Java.

A very complete life history of the moth borer as it occurs in the West Indies has been published by Maxwell Lefroy (*West Indian Bulletin*, Vol. I., No. 4); he describes the eggs as flattened, oval and slightly convex, about $\frac{1}{25}$ of an inch in length: they are laid in clusters on the leaf of the cane, the number being very variable, lying between 4 and 57 and being generally from 10 to 30. The eggs when fresh are light yellow, in thirty-six hours a tinge of orange appears and eventually they turn orange brown; in the final stage the centre of the egg becomes black. If the eggs are laid on young

cane the part attacked is the axils of the leaf or the leaf itself ; in the case of older cane the part attacked is the joint, the caterpillar eating its way into the cane and making tunnels up and down the cane from which it eventually emerges in from 30 to 35 days. The period of pupation, which takes place within the cane, is six days, after which the perfect insect emerges. The moth is inactive by day and living only four days lays in that time from 100 to 300 eggs. The underwings of the male moth are pale yellow, and of the female white; the upper wings of both sexes are an ochry drab ; both sexes are similar in size and appearance, the expanse of the wings being from 1 to 1½ inches. The damage done by the borer is not confined to the actual destruction of canes, but to the now established fact that the wounded cane is laid open to attacks of fungus ; in this connection the writer has examined many canes attacked by *Colletotrichum falcatum* and has never found a cane so attacked that had not previously been damaged by borer. Drawings of the moth borer and eggs on a leaf are shown in Figs. 20 and 21.

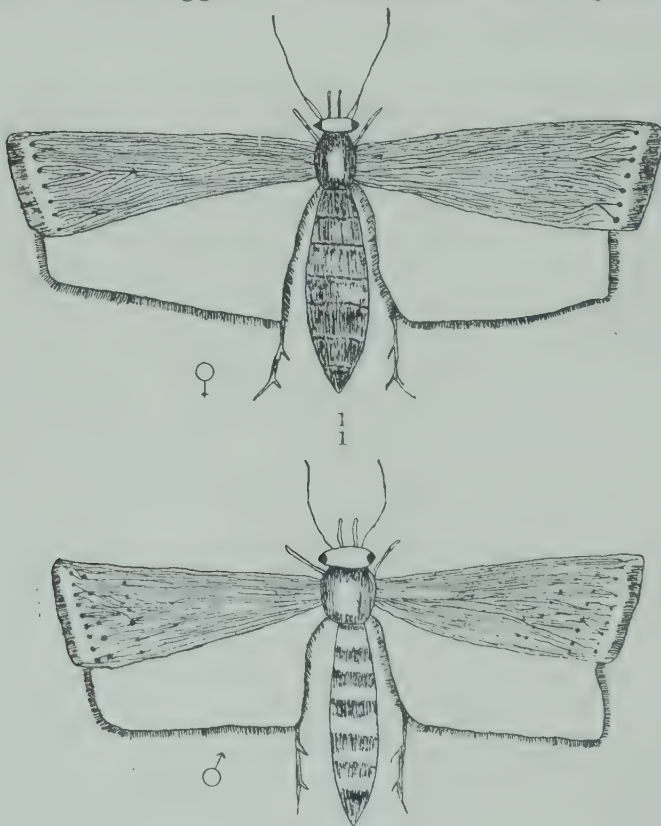


FIG. 20.

The enemies of the moth borer are also mentioned by Lefroy (*ibid*); two commoner ones are a chalcid hymenopteron, *Trichogamma pretiosa*, and a fungus *Cordyceps Barberi*. The first is a minute flying

insect which apparently lays its eggs in the eggs of the moth borer, these latter are destroyed, the parasite of the moth emerging as a perfect insect; the expanse of the wings of this insect is only about one-twentieth of an inch. A similar parasite of *D. striatalis*, called *Chaetosticha nana*, has been reported from Java by Zehnter.

The *Cordyceps Barberi* is a fungus which attacks the caterpillar; the caterpillar is completely destroyed, only its outer skin being left in a hard and dry condition.



FIG. 21.

The remedies to be adopted against borer are given by Lefroy :—

1. The plant canes to be carefully selected.
 2. All dried and decayed canes to be burnt as soon as possible after the cane has been cut.
 3. Cut out diseased canes.
 4. Soak the plant canes in an antiseptic solution before planting; this remedy was suggested with regard to rind fungus and does not affect borer.
 5. Encourage enemies, as *C. Barberi* and *T. pretiosa*; but attempts to spread them have not been successful.
 6. Destroy the stumps of canes which are not to be ratooned, as soon as possible; this advice was based on the habits of the borer in the United States, where the caterpillar hibernates in the stumps of dead canes.
 7. Catch the moth at night by exposing lamps over trays of molasses.
 8. Systematically collect and destroy the eggs laid on the leaves.
- Several other remedies are mentioned by Lefroy and rejected as useless.

With regard to 8, above, Lefroy discusses the risk of destroying eggs that have been parasitised by *Trichogamma* and so at the same time destroying the parasite. The method adopted in Java gets over this difficulty; all eggs collected are placed on plates and surrounded by a layer of molasses; the caterpillars are unable to pass through the molasses but the parasite emerges as a winged insect.

The *Apogonia destructor* is a black beetle occurring in Java which has been fully studied by Zehnter; the larvae cause great damage to the cane by feeding on the roots. Two main flights of these beetles occur in November and March, and it is between these dates that the damage is done. The beetle feeds at night and at sunrise burrows beneath loose earth; the eggs are laid in moist earth after the November flight; the larvae resulting feed on the cane roots for two or more months, emerging at maturity to cause the March flight. It is recommended to catch the beetles when they appear after rains and before the eggs are laid in December.

A root borer of the sugar cane and other plants common in Barbados has been carefully studied and described by the Rev. N. B. Watson, (*West Indian Bulletin*, Vol. IV., No. 1). This pest named *Diaprepes abbreviatus* is a lady-bird or weevil, and its life history is as follows:—

In August or September the perfect insect lays its eggs on the upper surface of leaves and after ten days the grub emerges and falls on the ground, immediately burrowing into the soil in search of food; the grub remains in the soil for three hundred and twelve days, eating the roots of cane, sweet potato, &c., and then pupates, the perfect insect emerging in fifteen days to repeat the same cycle. The grub at first is only $\frac{1}{18}$ inch long, reaching at maturity a length of one inch. It is extraordinarily destructive and one grub may destroy a whole stool of cane. As remedial methods the Rev. N. B. Watson (*loc. cit.*) quotes the use of lime as a general insecticide but places most reliance on a rotation, a crop being planted which does not afford food for the pest; as plants not attacked he mentions Ochro, Cassava, Yams, Eddoes, Woolly Pyrol, Pigeon Pea, Bonavist and Rouncival bean, and a bean *Phaseolus lunatus* which is very largely grown in Mauritius as a green manure. The enemies of the grub are ants and centipedes, and of the weevil lizards and toads, and Watson traces the increase of this pest to the destruction of its natural enemies by the mongoose.

The number of insects that attack the cane is very numerous, but except in the three cases quoted above their life history does not appear to have been worked out. Amongst others may be mentioned the shot borer beetle, *Xyleborus perforans* or *X. officinalis*, a small oblong beetle one-twelfth inch long; this beetle follows the moth borer and enters the cane, laying eggs in the interior which pass through the stages of larva and pupa. It is very doubtful if this insect as well as the lady-bird borer, *Sphenophorus sacchari*, attacks sound cane, the general opinion is that it prefers dead cane but previous experience has shown that similar insects not kept in check may develop a liking for the living plant. A variety of this insect, *S. obscurus*, and perhaps identical with it, has been reported from the Hawaiian Islands.

A cockchafer belonging to the genus *Melolontha* which attacks the roots of the cane has been reported by J. A. Despeissis as well as a small clavicorn beetle belonging to the genus *Brachypeplus*; this insect is from one-eighth inch to one-quarter inch long and itself feeds on decaying vegetable matter while its larvae bore into the cane.

Amongst other insect pests which are imperfectly known are the cane fly *Delphax saccharivora*, and the mealy bug *Dactylopius*.

Some sugar canes of Barbados origin were examined by D. S. Michael; he found amongst other insects a *Tarsonymus* and remarks that acari of this genus are great destroyers of vegetable life. They are extremely minute and transparent, and live in the leaf axil. A very similar species *T. Bancroftii* is found in Queensland and has been identified as the cause of the "red rust" which appeared there in 1877; a similar mite *Tetranychus exsiccator* has been observed in Java doing damage to cane leaves.

Another insect apparently confined to the islands of Mauritius and Bourbon is the pou á pou blanche or *Acarus Iceryi*; this is a minute insect attacking the roots of the cane and also boring into the cane by means of a long sharp proboscis and sucking the juice until the attacked cane is dry and dead.

The usual method, on the small scale at least, of destroying the smaller insect plagues is by spraying the infected plants with certain solutions. Icery in Mauritius recommended a solution formed by boiling lime and sulphur in water as efficacious against the pou á pou blanche and an emulsion of paraffin and soap is often recommended. The following receipt is recommended by Wakker. Genuine Persian or Dalmatian insect powder 100 grams; 200-250 grams raw spirit;

80-100 grams ammonia; allow to stand for two days; dilute with two litres of water and expose to the sun for a few more days; filter through cloth, squeezing out the residuum well; the dark brown liquor is extract of pyrethrum. Use 25 grams of this and 25 grams of soft soap per litre in aqueous solution.

The diseases of the sugar cane due to micro-organisms are very numerous and some of them are very serious; they have been chiefly investigated by the mycologists attached to the Java Experiment Stations especially Went and Wakker, by the experts at Kew, in particular Massee, and in the West Indies by Howard. On many points the authorities are at variance, all, however, agreeing on the great damage caused by fungus diseases and on the necessity for systematic prophylactic treatment.

The diseases that have been most studied are the Serch, the Red Smut, the Ananas or Pineapple and the Dokka Bong diseases of Java, the Root and Rind fungus of the West Indies, and the Gumming disease of Queensland; the cause and nature and the identity of these diseases are the points upon which the experts differ.

The diseases attacking the cane in Java are classed as leaf, stem, sheath and root diseases; the leaf diseases are not in general serious. Those which have been studied in Java are summarised below, the information being taken from Went & Wakker's *Ziekten van het Suikerriet op Java*.

1. *Djamoer Oepas*.—Large brown patches occur on the leaf and sheath, caused by a silvery mycelium found on the surface, the haustoria of which penetrate into the leaf, especially on the underside and on the interior of the sheaf. Later, small bodies (sclerota), first white, then yellow, and finally brown, are observed on the dead portions of the leaf; these spots are the size of a grain of mustard; the leaves attacked soon wither and die, but the damage is unimportant.

2. *Cercospora Köpkei*.—This disease occurs as dirty yellow spots, often meeting to form one irregular blotch, the centre of which becomes red. A brown mycelium is found on the leaf, the branches of which, sometimes isolated and sometimes united in bundles, carry colourless spores; the appearance of the underside of the leaf is as if it was covered with a white dust; the damage is not great.

3. *Pestalozzia sp.*.—This fungus forms irregular spots on the leaf, with withered centres with a brown border; it is a rare and unimportant disease.

4. *Uredo Kühnii*.—This organism lives on the ends of leaves and forms oblong flaws on the underside which are filled with brown or orange unicellular spores. It was at first thought that basidiospores were formed and the name *Uromyces Kühnii* was given to this organism. In Java, this disease is present everywhere in damp districts, but the damage is small.

5. *Leptosphaeria Sacchari*.—In this disease, dark green spots of several millimetres diameter make their appearance on the leaf; the contour of these spots is dark violet or red and they do not increase in size. Occasionally the leaf is completely riddled with dead spots. The mycelium grows in the tissue of the leaf. The perithecia have also their beginning in the leaf, and in an adult state occupy the entire depth. They contain a large number of asci, each one with eight bobbin-like spores. The damage done is very considerable.

Cercospora Sacchari.—This organism forms spots on the leaves surrounded by a reddish border prolonged into a yellow aureole, the shape of the eye on a peacock's feather. This organism is not found on the Cheribon cane or on the mountain plantations.

Eriosphaeria (Coleroa) Sacchari.—This organism forms dark red circular spots of one centimeter diameter. The mycelium forms spherical perithecia containing a large number of asci, each ascus containing eight spores.

The remedy recommended for all these diseases is the collection and burning of all infected leaves before the sporation takes place.

Another disease, characterised by yellow streaks and probably not caused by an organism, is prevalent in nurseries where considerable damage is done to young cane. This disease appears to be hereditary.

The diseases of the sheaf of the cane known in Java are:—

Cercospora vaginæ.*—This organism produces on the sheath large dark red spots which grow black at the centre; in the interior of the sheath is found a brownish fungus which produces oblong multicellular spores.

Red Rot.*—A disease caused by an organism imperfectly established. The disease appears on young cane with a preference for damp districts, attacking the young plants, stems and leaves. The stem is chiefly attacked at the soft parts near the nodes; the stem becomes red and the tissues which unite the ducts of the plant are destroyed. The disease is further characterised by the diseased sheath becoming

* See note at end of chapter.

orange and assuming the smell of mushrooms. At a late period of development the infected parts are covered with an abundant mucus mycelium, and eventually a large number of sclerotia the size of a pin head are produced, first white and then passing to yellow and brown. This disease does considerable damage to young plants, but is harmless after the cane is a few feet high. Disinfection with antiseptics and destruction of the infected sheaths is recommended as a remedy.

Acid Rot.—A disease much resembling the Red Rot and also incompletely diagnosed. It is distinguished by the brickred colour of the infected parts, by the larger sized orange coloured scleroties, and by the presence of an odour of apples. This disease does not readily pass to the stem, and then only attacks the young internodes; young shoots are, however, killed. The preventative measures recommended are the same as for the Red Rot.

Only one root disease of uncertain etiology is known in Java; it is characterised by the leaves withering while yet the stem remains healthy. After a time all the roots die, while new ones that may form ramify in an extraordinary manner. The stem meanwhile withers and becomes spongy. The damage is very considerable, and the treatment adopted is to earth up the affected canes so as to force a new set of roots from the lower part of the stem.

The diseases of the stem include the most serious of the parasites that attack the cane and call for detailed treatment. Three of these, the Red Smut, the Ananas, and the Sereh, have caused immense damage. The connection of the first two with the Rind Fungus of the West Indies and the *Maladie de la Gomme* of Mauritius is discussed later.

Ustilago Sacchari.—The organism which causes this disease is found in all the affected parts. The part of the cane which is most liable to attack is the top of the young cane, which is turned into a black, whip-like substance, covered with a greasy, foul-smelling stuff. The whole stool of cane is destroyed. The organism is also found on wild grasses which may be a source of infection to the cane fields. When this disease appears there is nothing to do but to burn the whole field. The writer has seen a seven-acre field of young cane in Mauritius absolutely destroyed. The disease is also known to occur in Queensland and Natal, and may do immense damage.

Marasmius Sacchari.—This is a disease attacking the foot of the cane and, so far as regards Java, appearing chiefly in nurseries. The

disease is characterised by the withering of the leaves of the young shoots and by the non-development of the buds. The cane plants contain in the interior a mycelium which also occurs as large white flakes on the surface of the cane. Adult cane is also affected, the roots being attacked and the cane dying from want of water. This disease, which may be very fatal, is referred to again when dealing with the West Indian Root Fungus. Walker's technical description of this fungus is, *Gregoria vel basi fasciculata, diversa, carnosomembranacea persistentes; pileus albus late-campanulatus dein sordide albus, planus vel cupuliformis, 15 mm. diam; lamellae albae simplices vel bifurcatae. Stipes centralis albus, long. 15, mm. apice tubiforme basi villosa. Hyphae albae. Sporidia hyalina, continua, irregulariter-oblonga utrinque attenuata, rotundata 16 — 20 = 4 — 5. Habitat in caulibus vivis.*

Top Rot or Pokka Bong.—The etiology of this disease is considered uncertain by Went and Wakker, although it is identified with the Gumming disease of Queensland, examined by Cobb and ascribed by him to an organism.

Bacillus vascularum.—Three stages are recognised. In the first, the young leaves become yellow, wither and die, and the internodes being unable to obtain food remain short and stunted; in the second stage the young leaves that have opened roll up and die; and in the third stage, the vegetative point is changed to a greasy pulp, the remainder of the top being filled with a greasy substance; later, the eyes underneath the top, shoot and form almost a new top. In Java the damage done is very small.

A disease referred to as *Streppenziekte*, of unknown origin and affecting the cellular tissue, is marked by the sudden death of the leaves when in full vigour, and on making a longitudinal section of the cane red and yellow stripes, similar to those described below under *Sereh*, appear; the early death of the cane occurs and considerable damage ensues.

The disease known as *Sereh* from the immense damage it has done deserves special mention. The symptoms of this disease as described by Benecke are:—

1. A low, shrubby growth, often only from 3—4 decimetres.
2. A fan-shaped arrangement of the leaves arising from a shortening of the internodes.
3. The internodes are only from $\frac{1}{3}$ to $\frac{2}{3}$ inch long.
4. The nodes are tinted red.
5. Numerous aerial roots are formed.

6. The fibrovascular bundles are tinted red.
7. Subterraneous outbranchings form.
8. The sheath and root buds turn vermilion.
9. In some cases there is no formation of wax on the stem.
10. The growing part of the stalk is frequently dyed red.
11. The leaf-sheath and the stalk stick together.
12. There is an accumulation of secondary organisms.

A great predisposing cause for attacks of Sereh appears to be bad drainage or a too great humidity; thus Koffmann found that canes next to the irrigation ditches were more attacked than others. Moreover, in the Cheribon district, where the disease appeared most prevalent, the land is chiefly low lying; elevated districts were less affected. Other causes that have been suggested are an excess of lime in the manures supplied, late planting, excessive ratooning and an insufficiency of silica in the soil. The one thing that appears certain is that ratoon cane is more subject to attacks than plant cane.

This disease has been investigated to a very great extent by the experts attached to the various experimental stations in Java. Treub ascribed the disease to the attacks of a nematode worm to which he gave the name *Heterodera Javanica*. Coinciding with the attacks of this worm he observed the presence of a fungus of the genus *Pythium*. This worm penetrated the bark of the root at places of accidental injury or at the growing point. After having arrived within the root the worm worked its way parallel to the central axis until it arrived at the point of growth of a lateral root. Soltwedel also attributed the damage to attacks of a worm to which he gave the name *Tylenchus sacchari*, stating that the parasite passed its existence in the root which it destroyed. The length of the *Tylenchus* is given by Soltwedel as about .7 mm. and its breadth as about .03 mm.

The connection between nematode worms and Sereh is not now generally accepted.

Janse ascribed the cause of Sereh to two organisms, *Bacillus Sacchari Janssi* and *Bacillus Glangae Janssi*, and stated that these organisms attack other plants besides the cane. He considered the seat of the disease lay in the reddened fibrovascular bundles. The dependency of Sereh on these organisms was controverted by Benecke and Migula, and is not now accepted generally.

Lastly, Went considered Sereh as a combined leaf sheath and root disease, and associated it with the presence of an organism *Hypocrea Sacchari*. His description of this organism is, Pulvinata, dein

depresssa, carnosae, pallide fuscae, stromatibus 2—4 mm. lat. 1 mm. crassis, saepe laeviter collascentibus, intus pallentibus vel albidis, pertheiciis fuscis, ostiolis vix prominulis $200 - 250 = 150 - 200$, ascis linearibus brevis pedicellatis $100 = 5$, sporidiis monostichis 8, e cellulis duabus inaequalibus mox decedentibus compositis, cellula superiori globosa 4μ diam., cellula inferiori cuboidea oblonga $6 = 4$, fumose-olivaceis, conidiis. *Verticillium Sacchari*.

Although the actual cause of Sereh is doubtful it is certain that it is extremely infectious, it having spread from district to district in Java. Certain varieties are immune, amongst which are the Canne Morte and the Manilla cane. Borneo canes, introduced into Java as a means of combating the disease, were found less immune than the already cultivated varieties.

The remedies which have been proposed are disinfection of the seed cane, destruction of infected canes and absolute prohibition of ratooning.

In addition to Java, the disease has apparently been noted in Queensland and India, and instances of fields with all the characteristics of Sereh are sporadic in Mauritius; Went has also observed Sereh attacking Black Java cane grown in Surinam.

The *Red Smut* has been carefully investigated by Went. He says that diseased plants do not show any outward sign of disease so long as they are not seriously affected. At a later stage the plant dies away, the leaves becoming prematurely withered and yellow. On cutting the cane longitudinally the joints are found to be affected, but two consecutive joints are seldom diseased. The disease shows itself in the shape of a red coloration in the interior of the joint, which is unequally distributed and darker in one place than another; peculiar white spots are also to be seen. This appearance serves to distinguish the disease from Sereh which is marked by a red stripe. The rind is unaffected and since the fibrovascular bundles are chiefly congregated near the rind the leaves are still able to obtain their food.

In the white blotches a mould is always present, a few threads of mycelium being found in the red patches. In the vascular bundles, brownish-black patches also occur, connected with which is a mycelium flourishing in the cells and walls of the bundles.

If a piece of diseased stem be allowed to dry, black streaks appear, due to stromata, from each of which spring a number of brownish-black straight hairs measuring from 100μ to 200μ in length and 4μ wide. Among these hairs arise a number of sickle-shaped conidia

measuring $25\ \mu$ by $5\ \mu$. If the diseased cane be kept in a damp place a white mycelium turning to grey appears, forming, in a few days, chlamydospores or resting spores. Went never obtained any form of spores other than conidia or chlamydospores, and because he failed to obtain the *Melanconium* stage, referred to later, concluded that the Red Smut was distinct from the West Indian rind fungus. To the organism described above he gives the name *Colletotrichum falcatum* and states that it is a wound parasite, only attacking canes already injured by the Red Rot or by insects. The organism has also a selective power for different varieties of cane. The complete description by Went of this, perhaps the most wide-spread and fatal disease of the cane, is: *Colletotrichum falcatum*. Setis nunc seriatis, nunc in pseudo-conceptaculum congregatis cuspidatis, $100 - 200 = 4$, fulgineis, sursum pallidioribus, conidiis falcatis $25 = 4$, hyalinis, ad basim setulorum, basidiis ovoideis $20 = 8$, hyalinis vel fuscis, suffultis. Habitat in culmis vivis.

The *Ananas* or *Pine Apple* disease is, like the former, a wound parasite, and its favourite place of attack is the exposed ends of cuttings for seed cane; fully grown cane is but rarely affected. When a cutting is attacked the interior at first becomes crimson red and then black, at the same time giving off a pleasant odour reminiscent of pine apples. An organism termed *Thielaviopsis ethacetica* and very similar to *T. basilica* attacking lupin roots in Europe, has been found by Went to be the cause of the disease. Cultures made from diseased canes remain white for from twelve to twenty-four hours and then turn olive green; this colour is due to macroconidia situated in the special cells at the ends of short branches of the mycelium. Microconidia are also formed in chains of three or more. They are formed at the top of a hypha and are rectangular and colourless. The complete description of this fungus is thus given by Went: *Thielaviopsis*. Hyphae steriles hyalinae vel pallide fuscae, septatae. Hyphae fertiles septatae non ramosae. Macroconidia ovata, fusca, catenulata, mox secedentia. Microconidia cylindracea vel bacillaria, hyalina, in interiore hypharum catemulatum generata et mox ex apice exsiliunt. *T. ethacetica*. Macroconidia $16 - 19 = 10 - 12$, microconidia $10 - 15 = 3$, $5 - 5$, in interiore hypharum $100 - 200\ \mu$ long. Habitat in culmis, fructibus, foliis in insula Java. Went has expressed the opinion that this may be the same as the *Trichosphaeria sacchari* of Massee; the writer has frequently met with this organism in Demerara and Mauritius.

As a means of preventing attacks of this disease which prevents the growth of the tops, the cut exposed ends are coated in Java, where the organism is prevalent, with a layer of tar made thin with arrack.

This disease has also been studied in Barbados by Howard, who identifies it with the *T. sacchari* of Massee. Howard was chiefly interested in finding a means of preventing the attack of fungus. He observed that in addition to the exposed cut ends, cracks in the rind formed a place of entry for the spores. As a preventative measure he recommends soaking the tops used for seed in Bordeaux mixture and covering the ends with a thin layer of tar; in this way a practically complete immunity is obtained; a less perfect immunity is conferred by the use of tar or Bordeaux mixture alone. Bordeaux mixture is prepared by dissolving 6 lbs. copper sulphate in 25 gallons of water and mixing it with 25 gallons of water in which 4 lbs. of lime have been slacked.

The *Maladie de la Gomme* or Gumming disease of Mauritius has been described as far as its external appearance is concerned by Bonâme. At first there is nothing abnormal in the appearance of the cane, but when the disease is fully established growth is stationary and the leaves turn yellow. If the stem is cut transversely small masses of a yellow viscid matter appear on the cut surface, which dry and harden in the air. This gum is only found in the central fibrovascular bundles and not in the sacchariferous cell. A gum, however, which is not yellow is also found round the knots and on the upper portion of the stem. In the final stages of the disease the extremity of the stem decays, the internal portion being filled with a grey viscid substance.

Diseased specimens of Mauritius canes were examined in Europe by Prillieux and Delacroix (*Bulletin de la Société Mycologique de France, Vol. IX.*). They identified the organism found on the canes with the *Darlucella melaspora* (Berkeley) found on Porto Rican canes and described it as *Coniothyrium melasporum*. They further state that it is very similar to the *T. ethaceticus* of Went and identify it with the *Trichosphaeria* of Massee connected with the West Indian rind fungus.

In the canes they examined they found a mycelium which on exposure to damp at a temperature of 15° C. developed a white growth turning to a light olive grey and afterwards developing a perithecium. The folds of the hymenium were covered with upright

cylindroid hyaline sterigmata of size $5\ \mu$ by $3\ \mu$ terminating in brownish ovoid spores $12\ \mu$ by $5\ \mu$ which germinate in three or four days; it is these spores that distribute the disease. They also observed chains of from five to ten conidial endocellular forms, each conidium was oval and slightly truncated, occasionally pear or barrel shaped and of size $18\ \mu$ by $9\ \mu$. Chlamydospores with a thick black membrane either round or polygonal and of diameter $15\ \mu$ were also found.

It should be noticed that Bonâme's description of the outward effects of the *Maladie de la Gomme* accord almost exactly with the description of the disease already referred to under the name Top Rot. Very possibly the organism investigated by Prillieux and Delacroix had followed on an attack of Top Rot and was not the original cause of the disease. This would be in accordance with Java experience.

The two great diseases known in the West Indies are the Rind and Root fungus. These have been investigated by Massee, at Kew (*Annals of Botany*, Vol. VII.), and later in Barbados by Howard (*Annals of Botany*, Vols. XIV. and XVII.). The Rind fungus is thus described in the *Kew Bulletin*, 1895, p. 81. "Canes infected with Rind fungus are first noticed by dark red or brown patches in one or two joints towards the middle or base of the cane. This red patch having made its appearance rapidly spreads upwards and downwards, the infected area darkens in appearance and is evidently rotten. Little black specks make their appearance between the joints, breaking from the inside to the surface."

A summary of the literature of Root and Rind fungus is given by Sir Thistleton Dyer in the *West Indian Bulletin*, Vol. II., No. 3 whence these notes are taken. Massee considered the Rind fungus to be due to a sphaeriaceous fungus which he named *Trichosphaeria sacchari* and found macroconidia in the interior and microconidia on the wounded surface of the cane. Both these forms he obtained in flask cultures inoculated with the *Melanconium* stylospores.

Went was of opinion that both the macro- and microconidia belonged to the fungus *T. ethaceticus*, already described as the cause of the pine apple disease, and judging chiefly from figures in Krüger's *Das Zuckerrohr*, Sir Thistleton Dyer thinks there is little doubt as to the identity of the two diseases. An organism observed by Went in Java as a saprophyte and called by him *Melanconium sacchari* is stated by Sir Thistleton Dyer to be entirely distinct from the *T. sacchari* of Massee.

The Root disease of the West Indies is thus described in the *Kew Bulletin*, 1895, p. 83. "The canes appear to receive a check in their growth; the plant dwindles down, fresh basal shoots are formed to supply the place of the dying ones, but notwithstanding this it is ultimately found that growth has been arrested and no cane formed and if the plant be dug up the roots are nearly all dead and those still living are dotted over by little red spots." From the examination of diseased specimens Massee identified as the cause of this disease the *C. fulcatum* of Went (a deduction the latter regarded as 'very improbable') and Sir Thistleton Dyer suggests that the cause of Root fungus is the use of diseased cane as seed, in which case following on what has already been noted the *Trichosphaeria sacchari*, *Thielaviopsis ethacetica* and *Colletotrichum fulcatum* are one and the same."

The whole subject has, however, been very ably studied in Barbados by Howard, and his researches leave no doubt that the root fungus and rind fungus of Barbados are entirely distinct; he positively identifies the rind fungus with the *C. fulcatum* of the Red Smut of Java, and is also positive that the *Melanconium* stage, supposed by Massee to be a phase of the rind fungus, is a distinct organism, not attacking living cane but only following on attacks of *C. fulcatum*. Howard's experiments are very conclusive and may be briefly summarised:—

1. On canes attacked by rind fungus two organisms are always found—a *Melanconium* and the *Colletotrichum fulcatum* of Went.
2. The *Melanconium* inoculated into living cane does not produce rind fungus, the damage being confined to the dead cells round the wound.
3. Canes infected with *C. fulcatum* reproduce all the features of rind fungus.
4. When canes are infected with *C. fulcatum* and afterwards with *Melanconium* spores, the latter grows.
5. The *Melanconium* always follows attacks of *C. fulcatum*, but does not itself attack living cane.

The root disease of Barbados is described by Howard as showing a predilection for ratoon cane grown in drier localities. Diseased stools are characterised by the leaf sheaf of the dead lower leaves adhering closely to the stem, being cemented thereto by a white, musty-smelling fungoid growth. The roots are found to have aborted, and the rind immediately over the undeveloped roots is marked by

brownish or blackish spots. After heavy rains colonies of small yellowish white toadstools appear on the lower parts of the diseased roots.

The fungoid growth cementing the leaf sheath to the stem was found by Howard to consist of a branched septate mycelium, which was also found on the roots.

By a series of experiments Howard proved the identity of the toadstool growth and the mycelium, and by means of infection experiments obtained all the symptoms of root fungus. He further identified the fungus with *Marasmius sacchari*, Wakker, already described.

As regards the relations between the sugar cane and disease, Howard points out the danger of using infected ratoon cane as seed, and shows that drought has an important bearing on the ascendancy or otherwise of the fungus; in a dry season when the roots develop slowly the fungus gains the upper hand. As remedial measures he recommends:—

- a. The use of the best cuttings for plant material.
- b. The cultivation of ratoons during the early period of their development.
- c. Starving the fungus in diseased fields by suitable rotations.
- d. The isolation of diseased areas.
- e. The search for disease resisting varieties.
- f. The comparison of surface cultivation, and mulching with dry trash during the dry season.

The West Indian rind fungus has also been described under the names *Strumella sacchari*, Cooke and *Trululla sacchari*, Ellis and Everhart.

Very great confusion has arisen over the identity and nomenclature of the root and rind fungoid diseases. However it seems perfectly clear now that

1. Rind fungus = Red Smut caused by *Colletotrichum falcatum*.
 2. Root fungus = Dokka bang = Foot Rot; caused by *Marasmius sacchari*.
 3. *Melanconium Sacchari* = *Strumella Sacchari* = *Trululla Sacchari* = *Coniothyrium Melasporum*; following on attacks of *C. falcatum*.
 4. Pine apple disease caused by *Thielaviopsis ethacetica*, identical with the macro- and microconidial stages of *Trichosphaeria sacchari*.
- The Gumming disease of Queensland was first investigated by Cobb (*Agric. Gazette of N.S.W.*, 1893-4) and afterwards by Greig Smith



FIG. 10.
ISCAMBINE.

3
1
SIZE

(*Int. Sugar Journal*, Nos. 47 and 48). The disease is characterised by the withering of the cane and by the exudation of small yellow drops of a viscid gum from the cut ends of the fibrovascular bundles. This disease has been definitely associated with a micro organism which has received the name *Bacterium vasculorum*. Greig Smith describes the organism thus: "The organism appears as an actively motile short rod and when stained and embedded in balsam has an average measurement of from $\cdot 4$ to $1\ \mu$. Carbol violet followed by dilute alcohol produces the best films, fuchsin stains the gum which adheres more or less to the dead cells, the blues stain but feebly. By using the night blue method on the scanty growth obtained on ordinary agar the flagellae can be easily stained. They are single and terminal. The bacteria are not coloured by the Gram method of staining. Spores were not obtained and are probably never formed." This disease is present also in Mauritius and is identified also as the Top Rot of Java.

Apart from questions of identity the cane producer wishes to know how to combat the fungus diseases; the methods to be recommended are:—

1. Good and careful cultivation tending towards a healthy plant.
2. Destruction of all diseased canes whether growing in the field or left over as rotten cane. To do this effectually combination is necessary; it is useless for one planter to destroy diseased canes if his neighbour does not.
3. When disease is prevalent disinfect tops by dipping in Bordeaux mixture or practice prophylaxis by coating the ends in a solution of tar in rum.
4. Plant fungus-resisting varieties. The Tanna canes have the reputation of being fungus-resistant; the Bourbon and White Transparent are specially prone to disease.
5. Systematically destroy the moth borer.
6. Rotation of crops. The peculiar proneness of the cane to disease lies possibly in the custom of growing cane continuously in the same soil, the fungus has then a continual habitat. If other crops were grown in rotation during certain periods the fungus would be starved and disappear. The practice of green manuring extensively followed in Mauritius and Louisiana has this effect.

* Mr. A. Howard informs the writer that the *Cercospora vaginæ* is very common in the West Indies; on the same authority Red rot is very common in Barbados, and Mr. Howard thinks that there is no doubt Went and Wakker are correct in considering the *sclerotium* fungus to be the cause of the trouble.

CHAPTER VIII.

THE TRANSPORT, HARVESTING, AND UNLOADING OF THE CANE.

The methods adopted for the transport of cane from the field to the factory may be divided broadly into two classes, animal transport and mechanical transport. These two classes may again be subdivided into road, rail and water transport. As a means of comparing these methods it will be convenient to take as a unit one mule power on roads. On an average a mule will draw a load of half a ton of canes at a speed of two miles per hour. On good, level, macadamised roads the speed and load will both be considerably greater, but a considerable portion of the transport will be over rough plantation roads, and very frequently on an up-grade. In wet weather, too, the haulage capacity is considerably diminished; the value of a mule power may then be estimated at one ton mile per hour. The value of the other methods of transport is shown in the annexed table in ton-mile hours, or in the equivalent number of mules on roads.

Method of Transport.	Ton-Mile-Hours.
Mule on road..	1
Mule on tramway, 2-foot gauge	15— 18
Mule on canal	18— 25
Steam Waggon	40— 50
Traction Engine, 6 nominal H.P.	60— 70
Locomotive, 3-foot gauge	200—250
Wire Rope	From 10 tons per hour and upwards

Comparing mule transport on roads and on tramways, very considerable information is given in *Bulletin No. 11., U.S.A. Dept. of Agriculture, 1885-6; Sugar Cane, Aug. 1886.*

The tramway there described was two miles long, of two foot gauge, with rails weighing 14 lbs. per yard; the average load in each car was 1900 lbs., the train load averaging 11·25 tons. This was drawn by two mules. If an average speed of a little over three miles per hour be allowed, the capacity of a mule hauling a load on a tramway works out at nearly 17 times the capacity on a road. The initial cost

of tramway cars and stock on the one hand, and of carts and increased stock on the other, is given at \$15,900 and \$15,800 respectively. The capital expenditure is then practically identical. The saving was due to the decreased number of carters and stock working per day, and amounted to a daily saving of \$22.75, 240 tons of cane being transported per diem.

Water carriage of cane is confined to Demerara and the Straits Settlements, and to a limited extent to rivers in Australia. In Demerara and the Straits cane is transported in flat-bottomed iron barges or punts holding from $2\frac{1}{2}$ to 3 tons of cane. The average load for one mule is four of these punts, which are drawn at a speed of from 2 to 3 miles per hour. The system of canals is shown in *Figs. 14 and 15*. To keep up a supply of thirty tons of cane per hour with an average distance of transport of two miles, not less than eighty punts will be required, with forty head of mules in constant work. This method of transport is one of exceptional cheapness so far as labour and upkeep of stock is concerned, when compared with animal transport on roads; but the upkeep of the navigation trenches and cross canals costs a very considerable sum. The punts, which are constructed of wrought iron plates and are put together on the estates, cost about £30 each ready for use,

Steam wagons and traction engines both belong to the same category and only differ in detail, the former being much lighter in proportion to power developed. A steam wagon of 40 I.H.P. and costing approximately £1,000 c.i.f., will draw a load of eight tons of cane or other material at an average speed of six miles per hour. These machines require, however, careful handling, and when they were introduced into Mauritius in 1902 met with frequent accidents, not from faulty design or construction, but owing to the type of labour available for driving; they were used on plantation roads, but these latter were in general found too rough and uneven for them to be used to the best advantage.

The capacity of traction engines, of course, varies with their size, but one of the size most commonly adopted, weighing about six tons and of eight N.H.P., will draw a load of about 20 tons, at an average speed of two to three miles per hour; like the steam wagons they are unsuited for any but good roads.

Undoubtedly the most important and efficient means of transport is a system of light railways. The gauge adopted generally lies between two and three feet; a gauge of two feet six inches is one

very commonly employed, but for large properties it is more advantageous to have a gauge of not less than three feet, as otherwise the number of wagons required becomes excessive. With such a gauge wagons having a platform area of 50 square feet can be used; such wagons will hold from two and a half to three tons of cane, a perfectly safe rule being to allow half a ton of cane to every ten square feet of platform area. A locomotive weighing approximately 15 tons will haul, at a rate of 10 to 12 miles per hour, 12 to 15 wagons, each holding about three tons of cane.

The cost of laying down a system of railways to feed a factory is very considerable. The lowest cost per mile for a gauge of two feet six inches is not less than £300, with rails weighing eighteen to twenty pounds per yard. For a three-foot gauge, with rails twenty-five pounds to the yard, an initial cost of £450 is the lowest which can be expected. These figures do not, of course, include the cost of locomotives and rolling stock. The cost of laying down the rails is entirely dependent on local conditions; where these are favourable, and no expensive cuttings or bridges have to be made, a minimum cost of £100 per mile may be sufficient, an estimate to be greatly increased with unfavourable local conditions.

The following figures, taken from actual practice, will give much information regarding light railway transport:—

Acreage served.	2050.
Miles of permanent track.. . . .	48.
Gauge.	3ft. 1½ in.
Number of locomotives	6.
Weight of locomotive	15 tons.
Number of wagons	175.
Size of wagons.. . . .	10 ft. by 5 ft.
Load of wagon	2·75 tons.
Number of wagons per train.. . . .	10.
Cane transported per 24 hours.. . . .	900 tons.
Average distance of transport	4 miles.
Cane transported.. . . .	48,000 tons.
Coal burned per ton mile	4·70 lbs.
Maintenance of line and rolling stock per ton mile	·772 pence.
Fuel per ton mile.	1·536 „
Stores per ton mile.	·160 „
Labour per ton mile	·740 „
Total cost of transport per ton mile	3·208 „

As a means of transport in hilly countries where ravines, gullies or rivers have to be crossed, or for connecting up outlying portions of an estate, wire rope transport is very efficient. This system consists of an endless wire rope running on pulleys supported on trestles about fifteen feet high. Suspended from the wire rope at fixed intervals are cradles or baskets which carry the cane; along one side of the wire are the loaded baskets continually following each other; they are discharged on to the carrier at the mill by tipping without leaving the wire and follow on to the other side of the wire back to the loading station. In this system the trestles carrying the rope are permanent, but the loading station is capable of removal as different sections are being harvested. To transport ten tons of cane per hour by this arrangement the following dimensions have been found satisfactory. The diameter of the rope is half-an-inch and costs 5d. per foot; the trestles made of wrought-iron stand fifteen feet high and cost roughly £6 each; they are placed about 150 ft. apart, there being then 35 to the mile; the pulleys placed on the top of the trestles along which the wire runs cost £1 per pair; the distance between the baskets or cradles is about 75 ft., equivalent to 70 baskets per mile, each basket carrying 200 lbs. of cane; the portable loading station costs from £20 to £30. The wire runs at a speed of from two to two and a half miles per hour. This system is often worked in conjunction with other methods of transport, as for instance in transporting canes brought by rail or water to a central point which is still removed from the factory.

In Mauritius large amounts of cane are transported over the Government railways, in trucks carrying on an average 12 to 15 tons of cane. The rates charged are ten cents of a rupee per ton mile for the first, eight cents for the second, and six for the third and following miles. This method is one of the cheapest.

Before passing on to the treatment of the canes in the mill, the labour saving devices connected with the harvesting and unloading of the cane which have been developed in recent years may be referred to. Cane cutters fall into two classes: portable hand cutters worked by power, and reapers. Of the former the Paul cutter developed in Queensland is an example; it consists of a knife to which a swift reciprocating motion is given, a rotary cutter being first tried and found unsuccessful. The motor used is a portable oil engine, power being transmitted to the tool by means of compressed air. The machines drawn or propelled by animal power all employ rotary

knives, cutting two rows of cane simultaneously. These machines besides cutting the cane are designed also to remove the tops. Provided canes could be made to grow uniformly upright there would be considerable prospect of success for these machines, but the tangled mass of cane so often met with in fertile land would seem to be a serious obstacle to their extended use.

Many arrangements are now in successful use for loading cane in the field; they are either operated by steam or animal power. In some forms the canes have to be brought by hand within the radius of the derrick, but others are provided with rakes which collect the canes, so that they may be clutched by a grapple. The grapple consists of a pair of curved forks, worked by means of two ropes, one of which allows the grapple to descend, the other closing and hoisting the loaded grapple.

Another application of the cane loader is in the transfer of canes from carts to tramway wagons; this method is described below in connection with cane unloaders.

With regard to the economy effected by these methods it must be remembered that they have been developed chiefly in Louisiana, where labour is expensive, and consequently the saving is more pronounced. The most favourable figures yet given claim that cane can be loaded at three cents. per ton. Now, in Mauritius, an average price to pay per ton is 20 cents. of a rupee, equal to, say, seven cents. of a dollar; but, then, it has been found by experience that mechanically-loaded cars do not contain nearly so much cane as hand-loaded ones, so that against the saving in labour must be put increased expense of transport. The really great advantage of these machines is, that in districts where labour is scarce, so many hands are set free for other work.

The appliances for unloading cane may be divided into hoists and rakes. In the hoisting class steel chains are placed across the floor of the car, the canes being loaded lengthways across the chains; when the car is in position to be unloaded the ends of the chain are pulled out by a hooked rod, battens being placed along the side of the car to facilitate this. The ends of the slings are then joined and attached to the wire rope of a hoist, the load is hoisted and transferred by a travelling crane over a platform or hopper, and a pull at a rope opens the attachment of the sling, when the cane is discharged.

The Link Belt Engineering Company, of New York, make several forms of cane discharger. In *Figs. 22 and 23* are shown photographs

of the installations at Carracas and Francisco plantations, Cuba. In *Fig. 22* the canes in slings are shown ready to be dumped into the hopper; the hoisting yoke is now parallel with the centre line of the shed; on being transferred by the travelling crane over the cars it is capable of being turned through at an angle of 90° . In other factories the position of the cars, with reference to the centre line of the shed, is at right angles to the position shown in *Fig. 22*; the hopper into which the canes are dumped is shown in *Fig. 23*. This arrangement obviates the use of the ordinary form of carrier.

A third modification also used by this company dispenses with the hoist altogether. Slings are placed in the car, as before. The cars are provided with drop sides, so that a continuous platform to the hopper is provided. The end of the sling, remote from the hopper, is attached to a wire rope passing over a pulley block fixed to the roof of the shed. The car is anchored to the ground, and a pull on the hoisting rope rolls the load of cane into the hopper. In *Fig. 24*

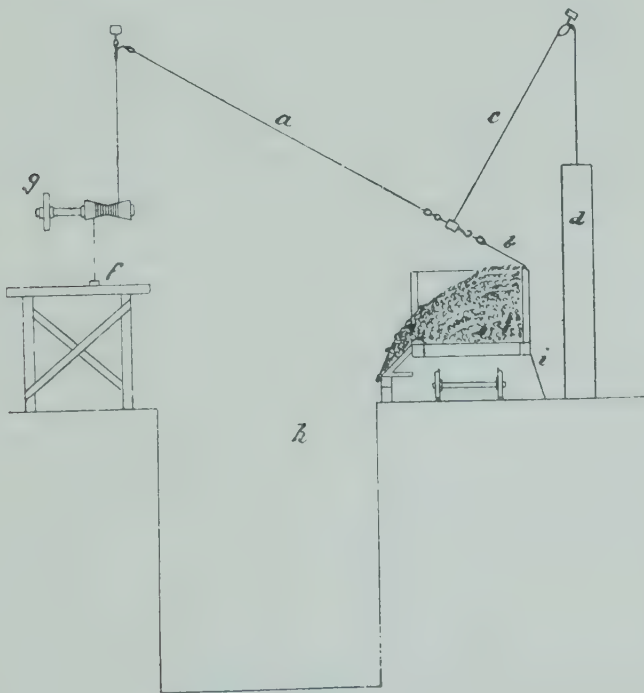


FIG. 24.

is a diagrammatic view of this arrangement; *a* is the hoisting rope receiving power from the sprocket wheel *g*; *b* is the free end of the cane sling; *c* is the counter-weight rope, and *d* the counter-weight box; *f* is the operating platform; *h* the hopper; *e* the drop-side of

the car, and *i* the anchor rope. In the cane dischargers, as made by the Bodley Wagon Company, no hoist is employed. The cane is loaded into cars which are provided with drop-sides. These sides form, when let down, a continuous platform from car to carrier. The carrier is sunk beneath the level of the ground. The unloading apparatus (Mallon's patent) consists of an endless chain passing over a frame which is hinged at its base, and is capable of being raised and lowered. On the endless chain are arranged a series of angle pieces called rakes. When a car is to be discharged the drop-side is lowered, the frame caused to descend on to the canes, the endless chain made to revolve, when the rakes drag the canes forward on to the carrier. The frames are made to correspond with the width of the car. This apparatus when installed at the Usine S. Madeleine, in Trinidad, unloaded 1200 tons of cane in 24 hours, effecting a saving of 64 hands. This apparatus has also been applied to the water-borne canes of British Guiana.

The *Walsh* unloader, in place of the rakes, uses a single row of curved prongs; to these prongs a simple to-and-fro motion is given. After the rake has passed once over the canes, it must be raised again, passed to the extremity of the beam on which it slides and lowered on to the canes, when it will drag on to the carrier another portion; the unloading here is discontinuous, and is opposed to the continuous discharge in the Mallon design.

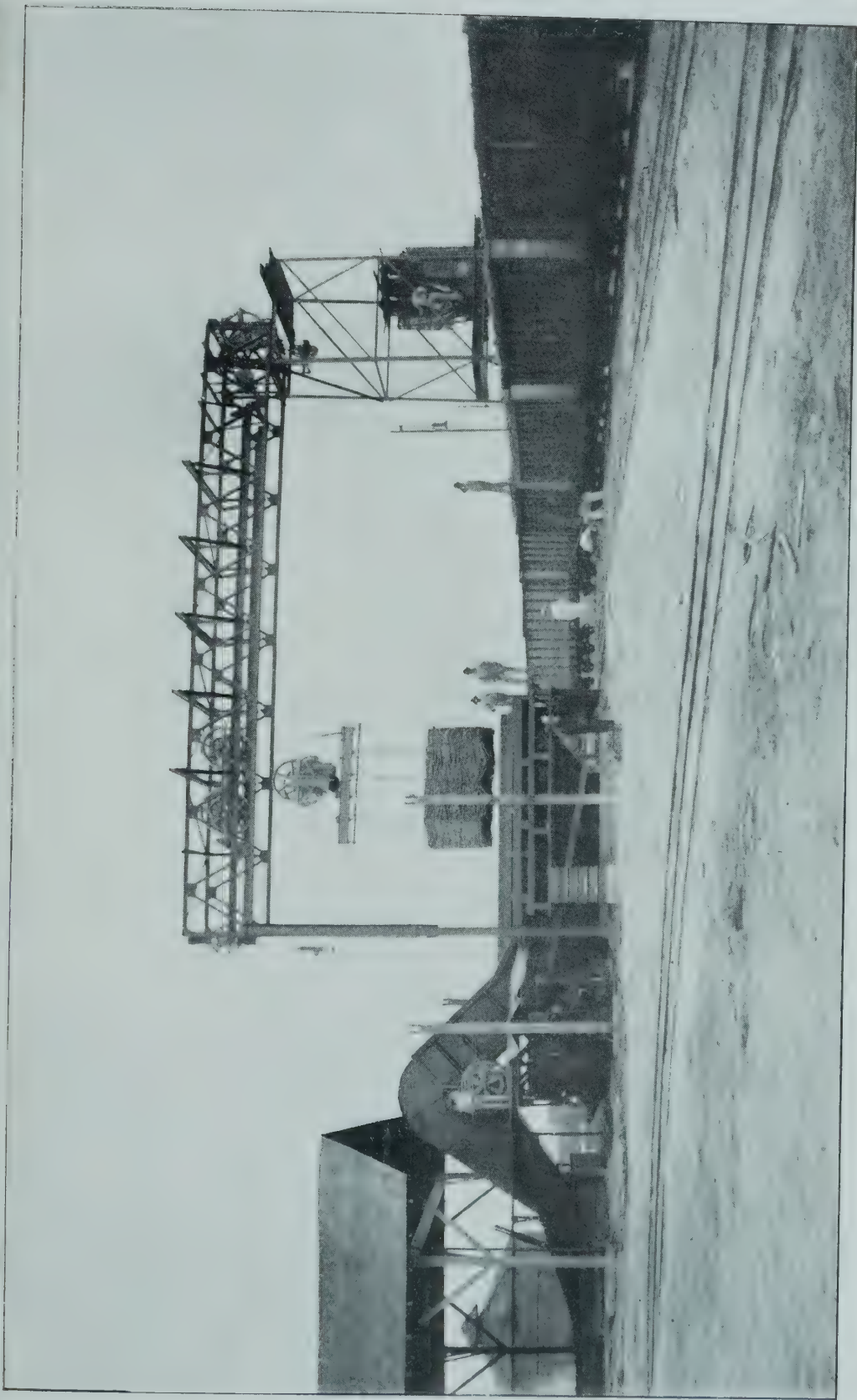


FIG. 22.—CANE DISCHARGER.

CHAPTER IX.

THE EXTRACTION OF THE JUICE BY MILLS.

Mills, as now constructed for the extraction of the juice of the cane, consist of heavy iron or steel horizontal rollers, driven by a steam engine through powerful spur and pinion gearing. The rollers are set with their centres at the angles of an isosceles triangle, the vertical angle of which is generally about 83° ; but, sometimes, mills are met with having a vertical angle considerably greater, even reaching up to 90° . The rollers draw the cane within their grip, subjecting it in its passage to great pressures, and causing the rupture of the cells and the expression of the juice; the latter falls on to the bed-plate of the mill, whence it flows into a well and is pumped up to the clarifiers for further treatment.

The favourite type of mill in recently-erected factories, especially in those under American control, consists of three three-roller combinations set tandem, all being driven by one engine; in other plants each mill has its own motor. The relative advantages of each system are discussed below.

In past times endless forms of mills have been devised—two, three, four and five rolls, and cycle mills with an even greater number of rollers; at the present day practically all the mills constructed are reduced to one type, which may be described as an open-headstock throughway-bolt type. This pattern is referred to by many writers as the Rousselot mill.* In Figs. 25, 26, and 27 are shown side and front elevations, and plan of a modern mill; the principal parts are the headstocks or mill cheeks, the rollers, the caps or keeps, the sole plate or bed plate, and the trash or dumb turner. The headstocks (*b*) are heavy solid castings; in them are three openings—one at the top and one at each side, which serve for the introduction of the rollers (*a*). The rollers consist of a shell of iron or steel, which is forced by hydraulic pressure on to the shaft or gudgeon; formerly the shell was hung on the shaft by six or eight keys, and occasionally in old mills square shafts are to be met with. The shaft, which is also

* The Rousselot patent referred to the side cap throughway bolts, of which there were four. The modern tendency is to employ four vertical throughway holding-down bolts, between which pass the two side cap bolts.

called the gudgeon, is constructed either of hammered scrap-iron, wrought-iron, or in the most recent designs, of fluid compressed steel. The shafts are nearly always made solid, as no benefit is obtained by a light, hollow shaft, and it is desirable to keep their diameter as small as possible, consonant with sufficient strength. The shafts rest on brasses (*h*) of gun metal of large bearing surface; to one end of the

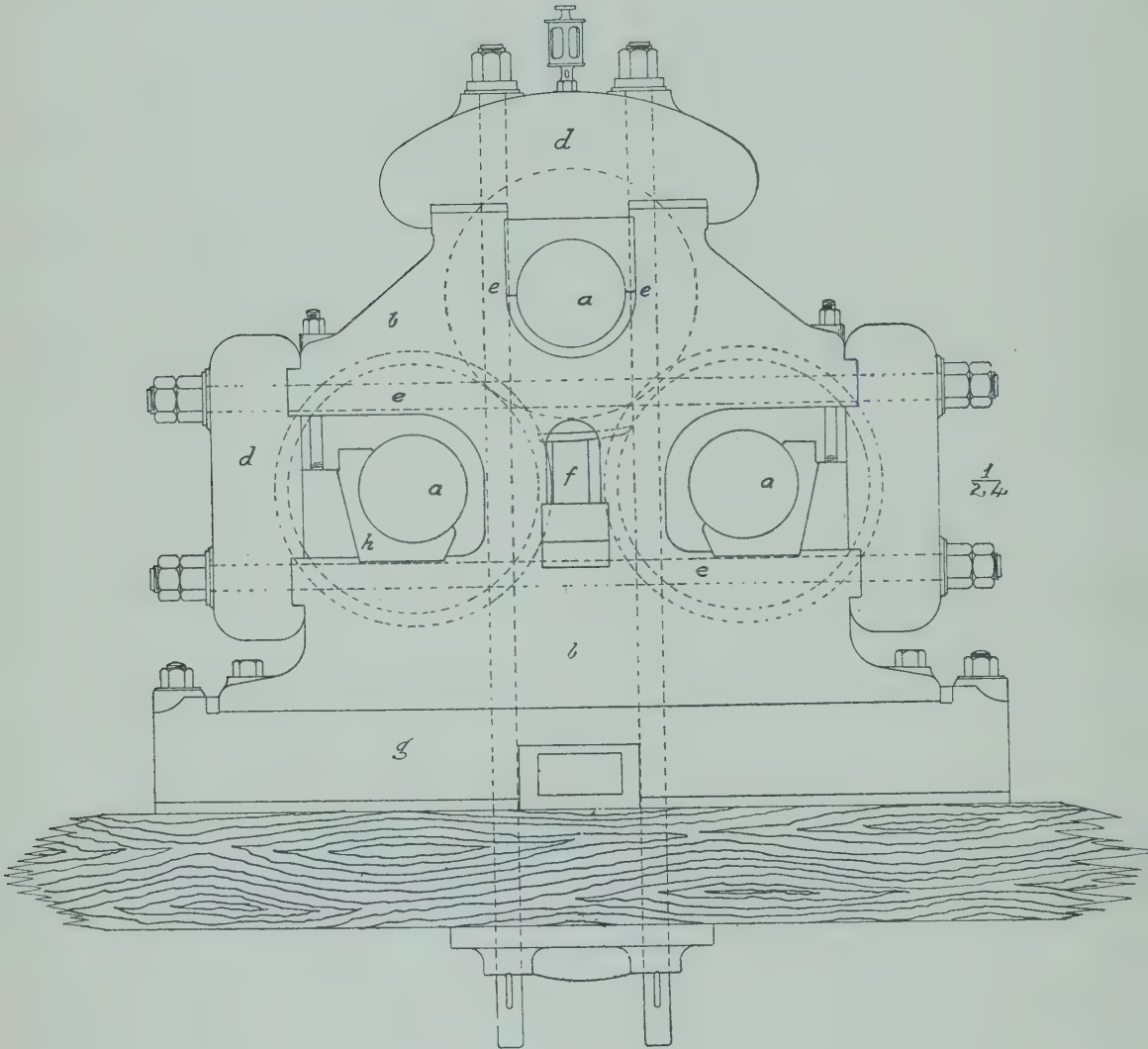


FIG. 25.

shafts are keyed pinions gearing into each other, by means of which motion is transmitted from the top shaft to the two lower rollers. Generally mills are geared on one side only, but occasionally gearing is found on both sides. The rollers are kept in position by the caps (*d*); through these caps pass throughway bolts, which keep the caps pressing on the bushes. The position of the rollers is adjusted by means of these bolts. The headstocks rest on the sole plate (*g*), to

which they are securely bolted; all the vertical bolts pass through the foundation and act as holding-down bolts. The trash turner consists of two parts—the trash bar (*f*) and the trash plate, the curve of which is also shown. The trash bar is a heavy rectangular steel bar, which is supported in recesses arranged in the headstocks; the trash plate is a curved steel plate bolted to the trash bar. The

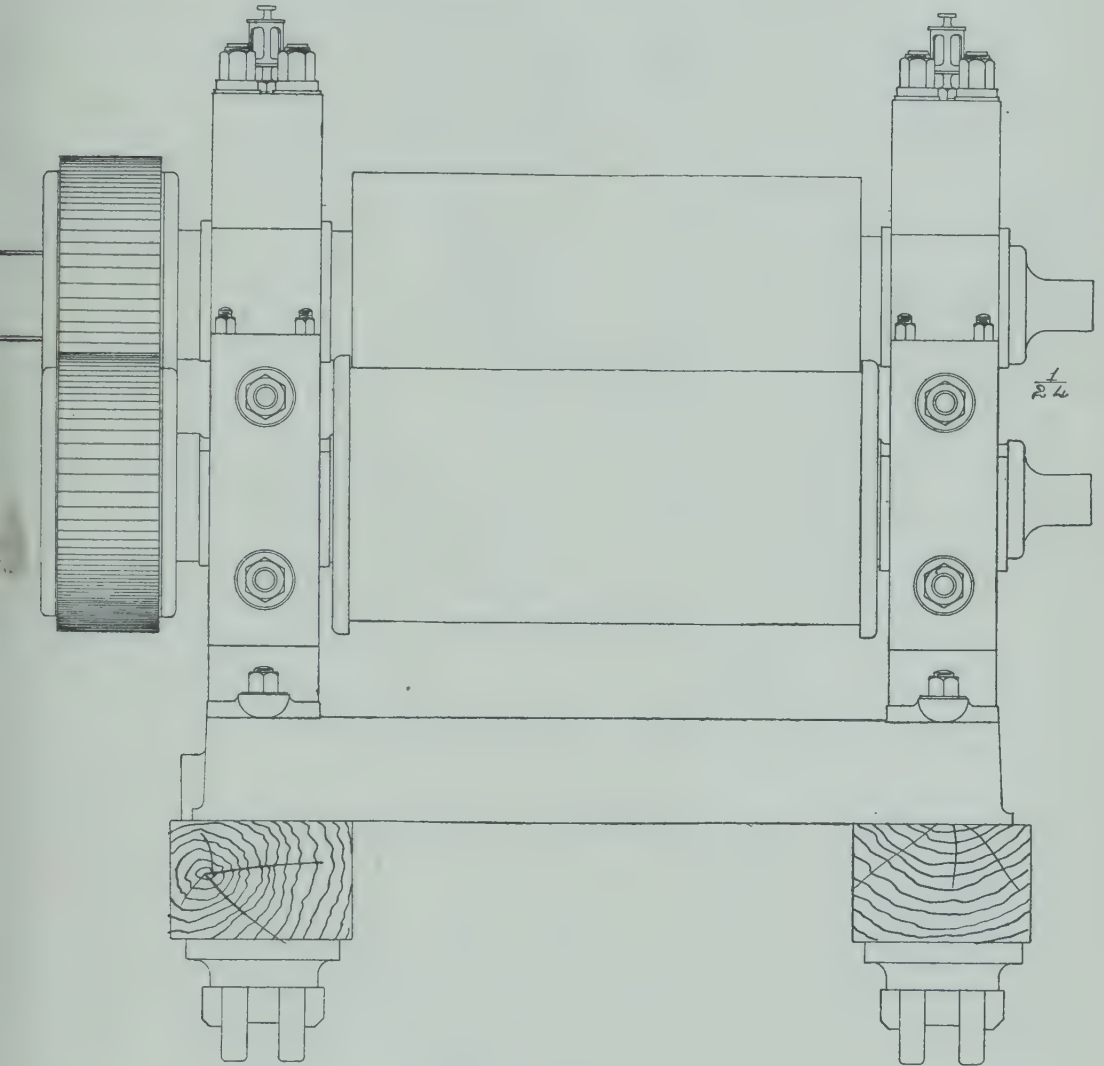
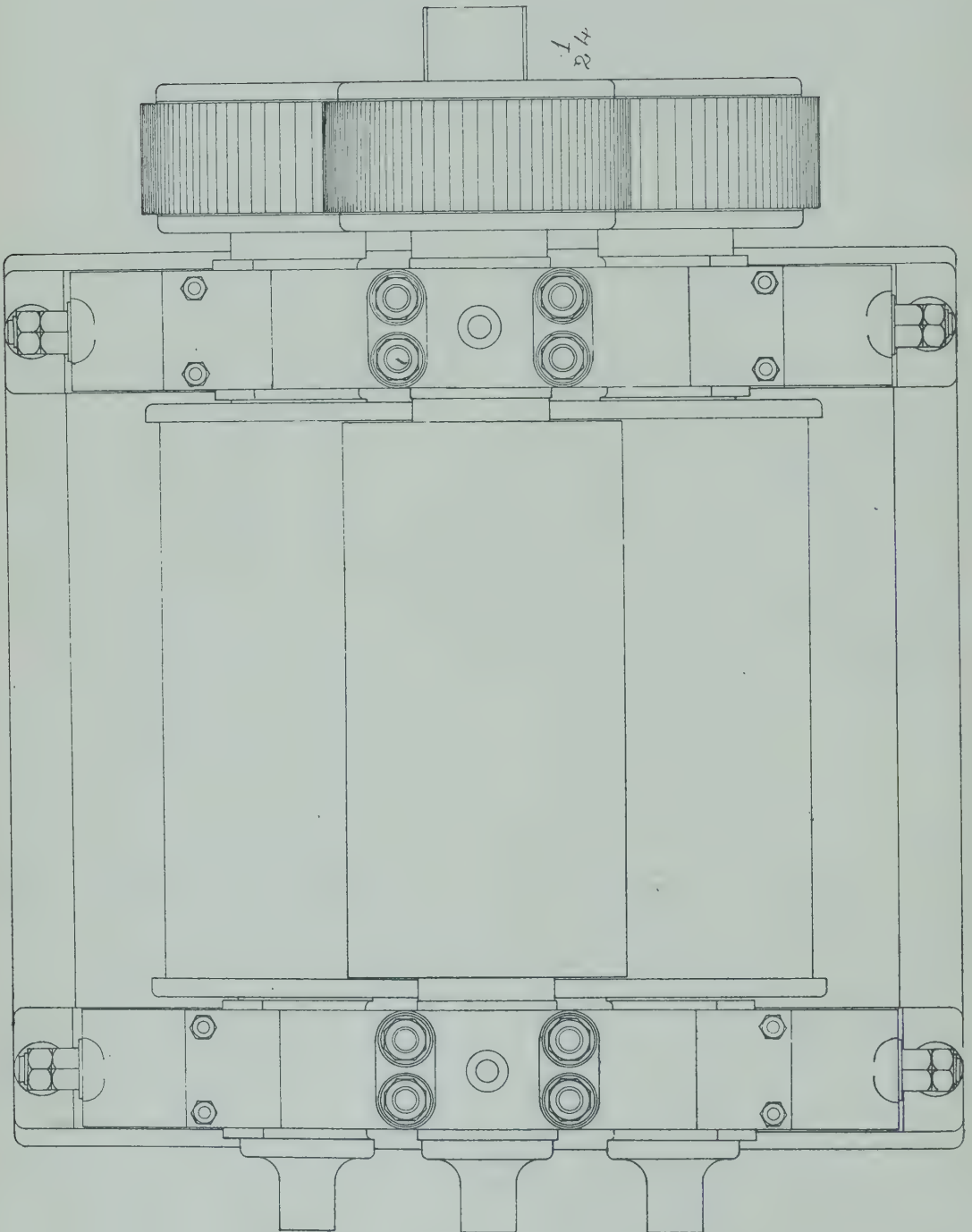


FIG. 26.

whole is adjustable by means of inserting or removing wedges in the recesses supporting the trash bar, so that the trash turner can be set at any desired angle or distance from the rollers. Its object is to direct the partially-crushed megass between the top and back roller. A vast number of curves for the trash plate have been tried, and a great difference of opinion as to the proper curve exists. A large number of engineers hold, on certain mathematical reasoning, that



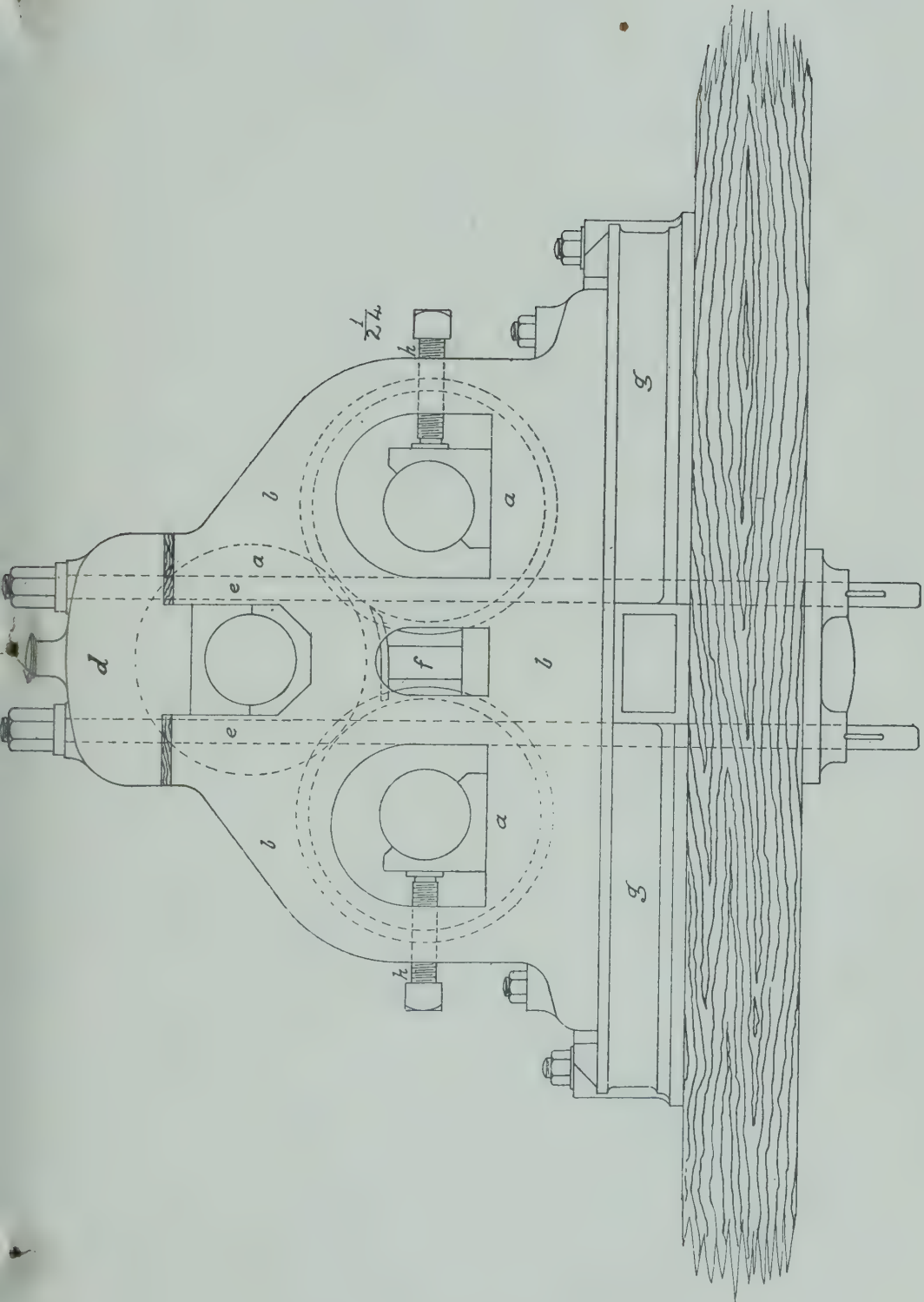


FIG. 28.

the curve with which least power is absorbed is a logarithmic spiral ; another method is to form a new trash plate in a curve similar to that into which the old one has been worn. The trash plate is usually set sloping slightly downwards, leaving a clearance between itself and the back roller, so as to allow juice to flow away freely.

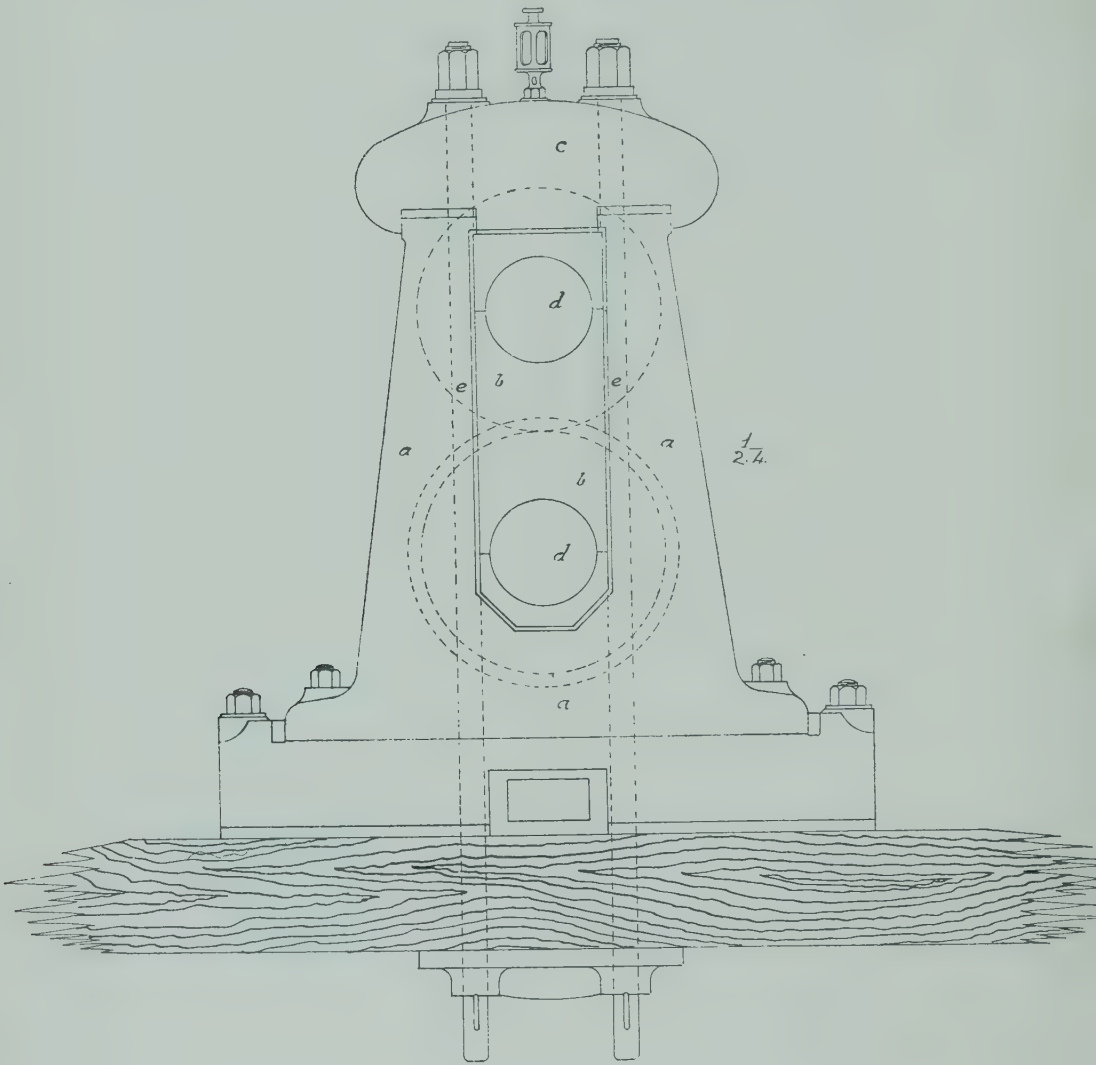


FIG. 29.

In Java, a distance between trash turner and top roller, measured along the vertical line through the centre of the latter of about 55 m.m. (2.45 inches) for mills 30 in. $\times$ 60 in. (crushing about 600 tons in 24 hours) has been found very satisfactory ; for every 1000 piculs (60 tons) increase in cane milled per 24 hours the distance between trash turner and top roller is increased 3 m.m. ($\frac{1}{8}$ inch) or so.

The older type of three-roller mill is shown in *Fig. 28*; it is referred to as the closed headstock pattern; the side rollers are kept in place by means of set screws passing horizontally through the headstock. Mills of this type are still occasionally built, and perform, as far as crushing is concerned, as well as the more recent open headstock pattern. In the latter, however, the strains are taken up by the thoroughfare bolts, and in the former by the headstock, which, with sudden strains, was liable to fracture.

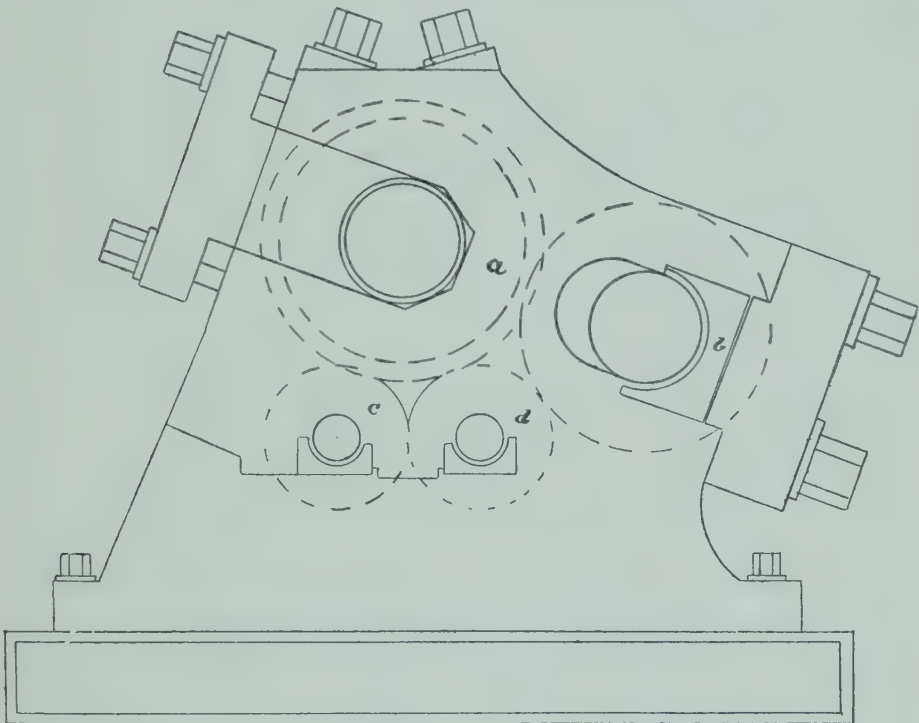


FIG. 30.

In a three-roller mill, a very great proportion of the power required to drive it is absorbed in friction between the megass and the trash turner. An attempt to dispense with the trash turner is seen in Allan's patent. This mill may be described as an ordinary three-roller turned through an angle with the original vertical roller reduced in size; the two side rollers then come nearly in the same vertical line with the centre of the original vertical roller approximately in the same horizontal line as the line of contact of the other two rollers; the small roller is then able to act as a feeding roller to both the larger rollers. Although this arrangement dispensed with the trash turner, it has never been largely adopted. Two-roller mills (*Fig. 29*) have in time past obtained many advocates

who held that the strains would be more evenly distributed, and that the power lost through the trash turner would be saved. In addition the rollers being in the same vertical line, it was argued, perfectly correctly, that the whole of the pressure keeping down the top roll would be exerted in crushing the cane; experience has shown, however, that they are not successful, one very potent objection being that the rollers cannot be set close, else the mill refuses its feed; whilst in a three-roller mill, the front roller acts as feeding

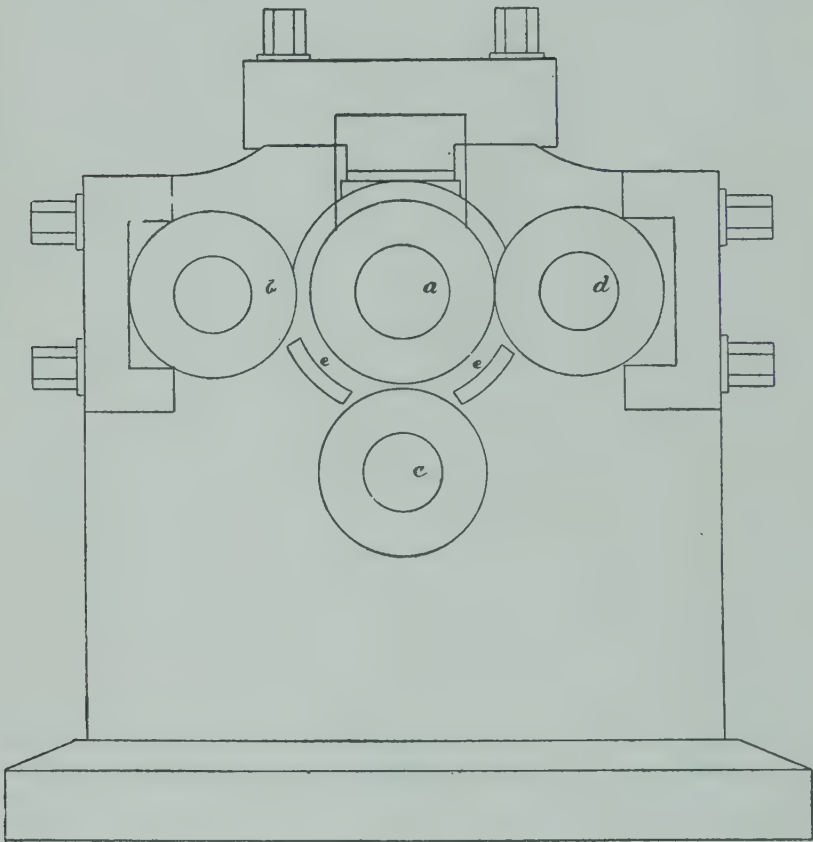


FIG. 31.

roller to the back one. Of four-roller mills, which have never come into general use, the best known are the *De Mornay* and *Le Blanc*. The former, which has been erected to some extent chiefly in Peru, Argentina, and Brazil, is shown in *Fig. 30*. It consists of two main rollers (*a* and *b*), and two supplementary rollers (*c* and *d*). The cane is crushed three times, between *a* and *c*, *a* and *d*, and *a* and *b*; no trash turner is required. This mill has given good results with long jointed canes, but with short jointed hard brittle canes it has not been successful.

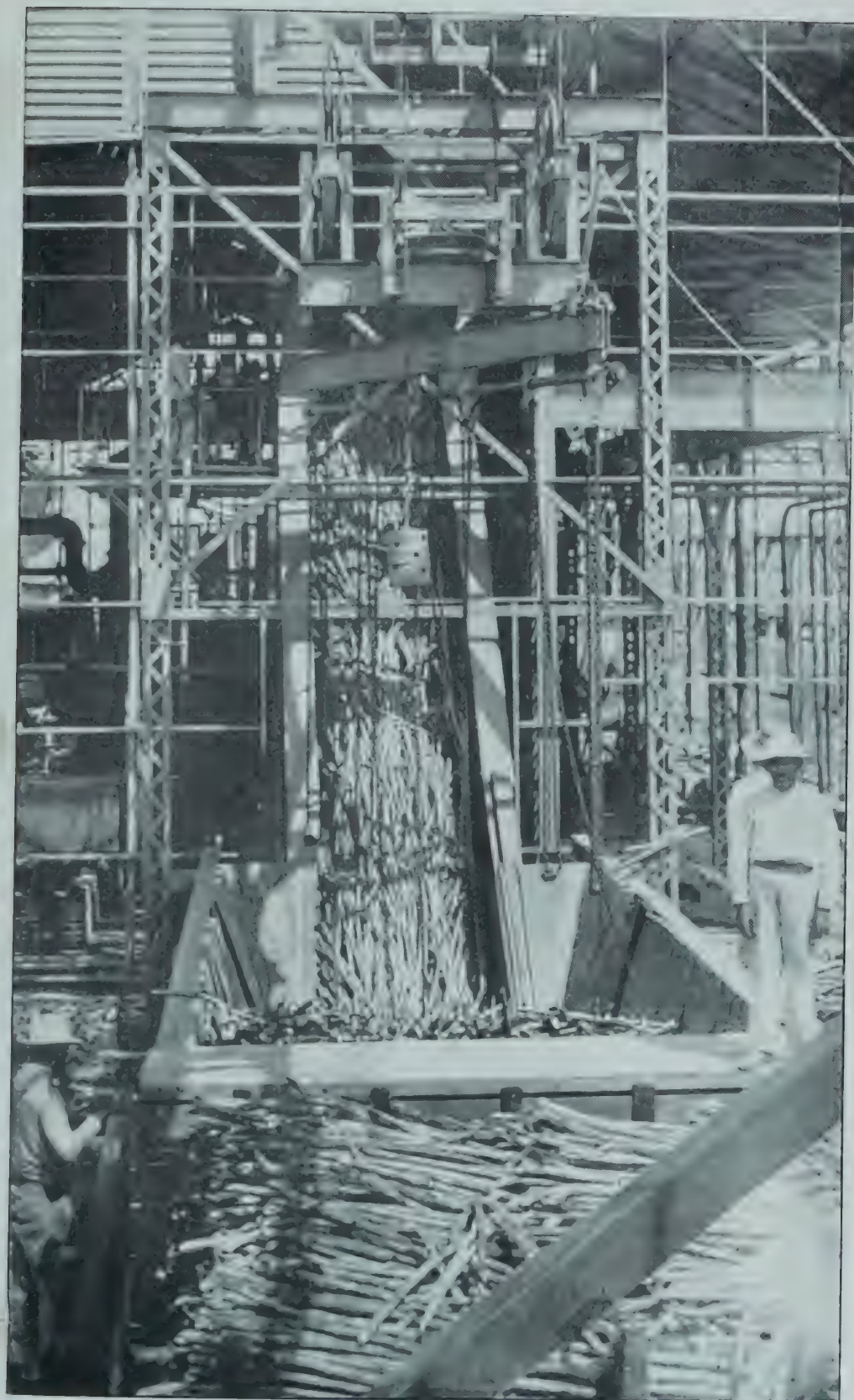


FIG. 23.—CANE DISCHARGER: THE HOPPER.

The *Le Blanc* mill is shown in *Fig. 31*. It consists of a main central roller (*a*), round the periphery of which are placed three other rollers (*b, c, d*); the cane passes between each of these and the main central roller, so that it is crushed three times. Two trash turners (*e*) are required. Of five-roller mills, that known as *Thomson's & Black's* may be mentioned. In this design the headstocks are extended so as to receive a pair of rollers, which are placed above and in front of an ordinary three-roller mill; the gudgeon of the top roller of the mill proper is extended on one side so as to receive a large spur wheel, which gears with one of equal diameter on the gudgeon of the top of the two preliminary rollers. On the other side of these rollers are pinions gearing with each other, by means of which motion is transmitted to the lower of the two rollers.

With the exception of a few instances in unprogressive districts, steam is the agent used to drive sugar mills; wind power is still employed to some extent in Barbados, and where water power is available no objection can be made to its use. Electrically-driven mills still belong to the future, but the design of one prime motor, to drive electrically all the machinery in a factory, offers no great difficulty; and, where water power is available, the design of a system of turbines, dynamos, and motors to drive all the engines and pumps in a factory without burning any fuel for motive power, is quite feasible.

The engines used to drive sugar mills are either beam engines or horizontal engines; generally, owing to the type of labour available, the design of the engine is as simple as possible. Whether beam or horizontal they are nearly always simple non-condensing engines, the exhaust steam being used in evaporation. Beam engines make a handsome ornament to a factory, but they are more expensive in first cost; their cylinders, however, do not require re-boring. The horizontal engines used are nearly always single cylinder engines; occasionally, when the engine is at a dead centre, the cane mill chokes, and it may be necessary to lever the fly-wheel round to allow the engine to re-start. A two-cylinder engine with cranks, set at right angles, would overcome this difficulty. Double and triple compound non-condensing engines have also, in a few instances, been erected.

The intermediate gearing, which transmits power from the engine to the mill, consists of heavy toothed wheels; occasionally helical teeth are employed. Except in small plants, the spur wheels are

built up in segments; usually there are from six to eight arms, to which are bolted the segments of the gearing; the pinions are cast in one piece, and are usually half shrouded. In *Figs. 32 and 33* are

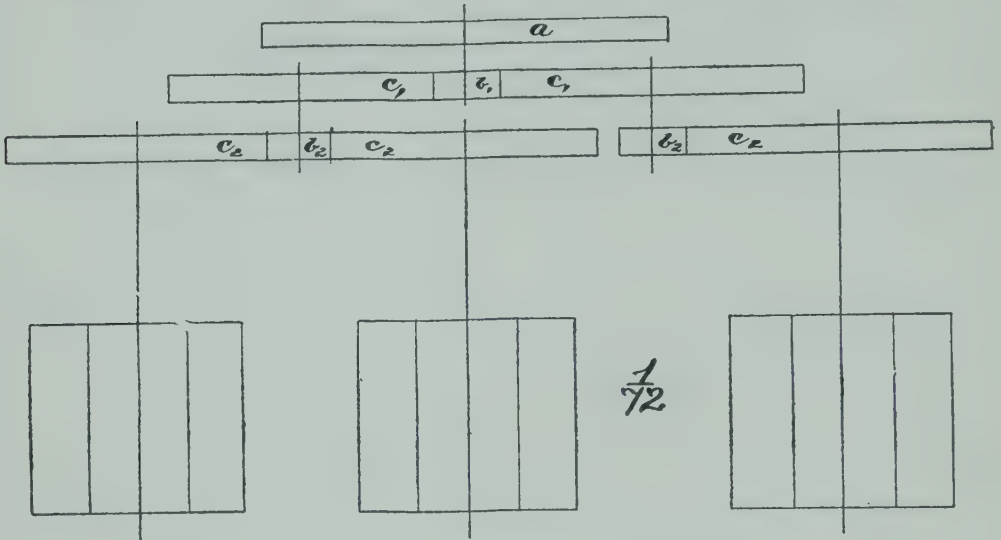


FIG. 32

shown two methods of connecting up the gearing of a single motor nine roller mill; (*a*) is the fly-wheel, (*b₁*) the first motion pinion, (*c₁*) the first motion spur wheel, (*b₂* and *c₂*) the second motion pinion and spur wheels. In *Figs. 32 and 33*, *b₁* transmits motion to both spur wheels, which in turn convey power to the spur wheel *c₂* by the pinion *b₂*. The ratio of gearing is 20:1, and with an engine revolution of 40 per minute gives a peripheral speed to the rollers 30 inches in diameter of 15.7 feet per minute; in the gearing as arranged in *Fig. 32*, a much more compact train of gearing results, and this is the form usually adopted in modern plants. As a modification, the first motion gearing can equally well be connected to the pinion between the first and second mills, and in the scheme in *Fig. 33* the greater distance between the two mills may be between second and third or first and second, dependent on whether the mill at extreme right or left is considered to be the first mill; in either case the distance between the two mills closer together can be increased by increasing the size of the spur wheel without altering the speed of the mill.

The purpose of the arrangement in *Fig. 33* is to obtain a means of complete maceration in baths between the mills, an object which cannot be attained by the more compact system illustrated in *Fig. 32*. This question is discussed at greater length further on.

It is now a fairly general rule in single motor-driven plants to arrange the gearing so that there is a slight increase in the speed of the rollers from mill to mill, the object being to reduce the thickness

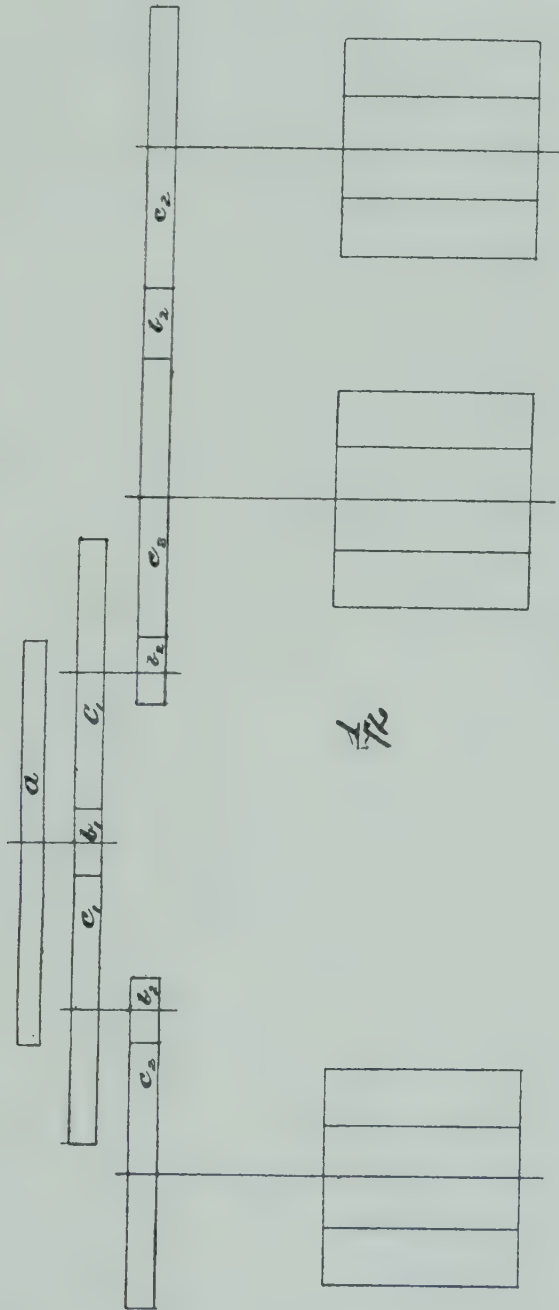


FIG. 33.

of the blanket of megass and prevent choking. The size and surface speed of the rollers is an essential point in mill design. Some engineers hold that better results with high speed and small feed are obtained than with low speed and big feeds. Formerly peripheral speeds of 14 to 15 feet per minute were usual, but now many mills

are built to run at as high a speed as 20 to 25 feet per minute. The question can be looked at in this way: let there be two identical mills both crushing similar amounts of cane, but running at different speeds. Let the mills be of size 60 in. $\times$ 30 in., and let the tons of cane passed per hour be 25; in the one case let the revolutions per minute be 2, and in the second case $2\frac{1}{2}$, and in both cases let the megass be crushed to a fibre content of 45%; then, if the canes contain 12% fibre, three tons fibre pass per hour, and 3.66 tons juice of density (say) 1.07. The fibre is approximately 1.35 in density, so that the volume of the megass passing is:—

$$\text{Fibre } \frac{3 \times 2240}{62.25 \times 1.35} = 79.96 \text{ c. ft., and}$$

$$\text{Juice } \frac{3.66 \times 2240}{62.25 \times 1.07} = 123.19 \text{ c. ft.}$$

or together 203.15 c. ft.

The crushing surface per revolution is $\frac{\pi \times 30 \times 60}{144} = 39.28 \text{ sq. ft.}$, so that, with a speed of 2 revolutions per minute, the minimum opening of the rollers must be $\frac{203.15 \text{ ft.}}{39.28 \times 120} = .043 \text{ ft.} = \frac{33}{64} \text{ in.}$

With a speed of 2.5 revolutions per minute, the minimum opening becomes $.034 \text{ ft.} = \frac{26}{64} \text{ in.}$ Now the megass and top roller are generally set metal to metal so that this opening, the least possible, must be given by the spring or elasticity of the mill. With high speeds the distortion of the mill is less, which would seem to be an argument in its favour; on the other hand, as the distortion of the mill becomes greater the pressure exerted increases, so that *cæteris paribus* it would seem that the thicker blanket of megass would part with more juice, provided, of course, that the mill is not strained beyond its elastic limits.

A very general proportion for the size of rollers is that the length be twice the diameter. Increasing the diameter of the roller calls for greater power to drive, and at the same time increases the tendency to fracture, due to torsional strains; at the same time the gudgeons can be made larger, and, whereas the torsional strain only increases directly with the diameter, the strength of the gudgeon increases proportionately to the square of the diameter. Another objection to rollers of large diameter is, that the trash turner also becomes larger, and friction is here materially increased; on the other hand, the curve of large rollers being flatter, cane is a longer time in contact

and under pressure, and the rollers being further apart there is less risk of re-absorption, but at the same time, owing to the flatter curve, juice flows from the rollers less easily. A very favourite size in recently-erected plants is a roller 78 in. $\times$ 32 in., experience having apparently shown that increase in diameter above this size is not attended by better results. When not increasing the diameter in proportion to length, the diameter of the gudgeons, and consequently their strength, does not increase in proportion to horse-power transmitted. A roller of such dimensions must essentially have its shaft made of the very best material; such a proportion with inferior material would only result in inferior work or in breakages.

The size and setting of the trash turner is a point of very considerable importance. In the first place its object is to direct the partially crushed cane between the top and back rollers, and it is usually set sloping slightly downwards in the direction in which the cane travels. If it is set too close to the rollers there is insufficient room for the blanket of megass to pass without causing enormous friction, and if set with too great a clearance it ceases to perform its proper functions. As friction depends on the area of contact, its width should be as small as possible. The width of the trash turner is determined by what may be called the vertical angle of the mill, *i.e.*, the apex of the triangle formed by joining the centre of the rollers; the larger this angle, the wider the trash turner. In actual practice, vertical angles lying between 75° and 90° are met with, a very general angle being about 82° - 84° . In addition to a small vertical angle diminishing the width of the trash turner, the component of the downward pressure exerted vertically on the top roller, on the line joining the centres of two rollers, is greater. There is a limit, however, to decrease in the vertical angle since, as this narrows the space available for the shaft of the lower rollers becomes less. By the employment of the best material, mills with small shafts of sufficient strength and narrow trash turners can be made. To obtain a narrow trash turner, mills have been constructed by inclining the holding down bolts vertically towards each other, and also by extending the top cap and placing the holding down bolts outside the shafts of the two lower rollers.

Of special appliances adapted to cane mills, the hydraulic pressure regulator, the toggle gear of the Mirrlees Watson Co., and the automatic feeding devices called "*Pushers*" deserve notice. In *Fig. 34* is given a view of a form of hydraulic appliance. Instead of the roller being

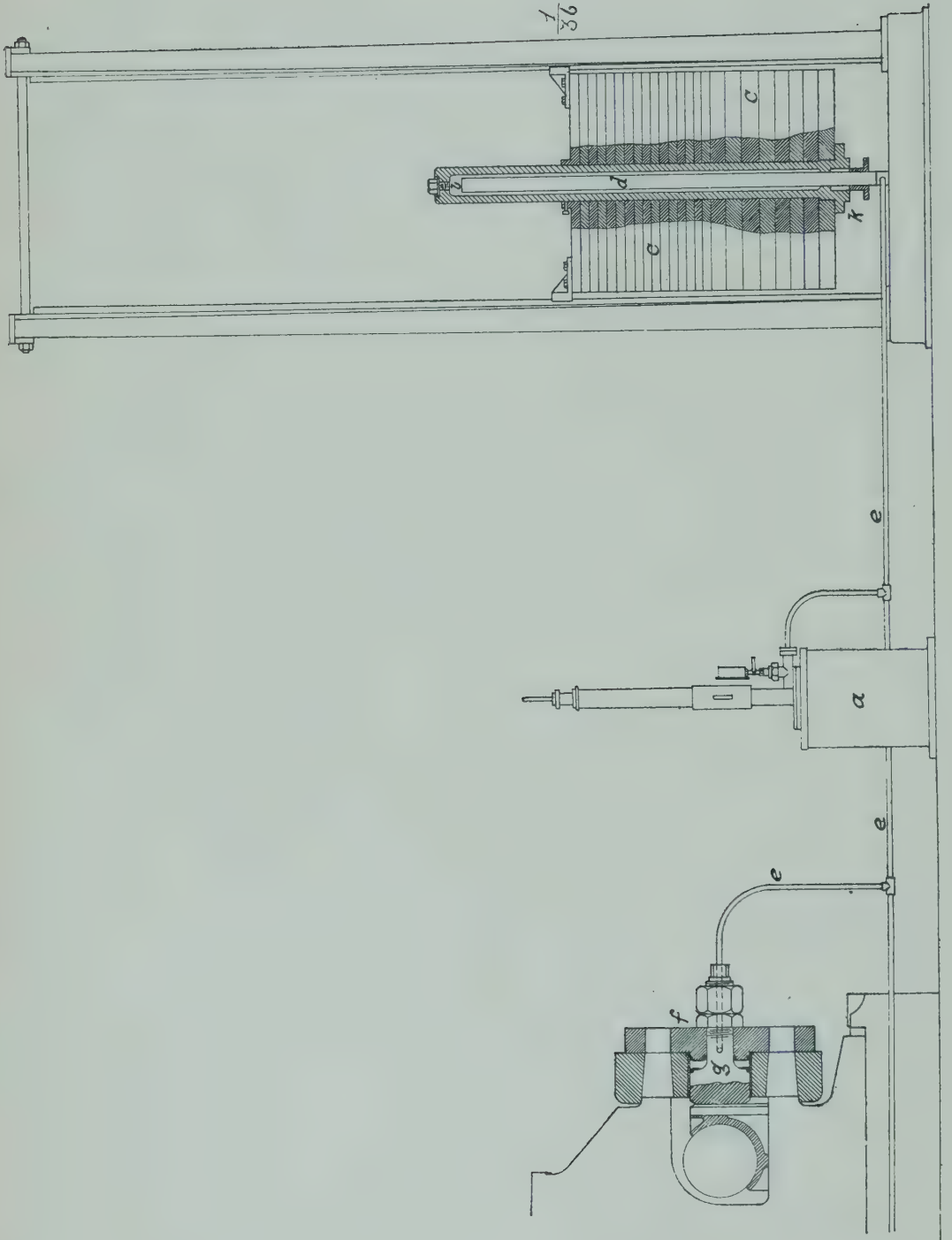


FIG. 34.

kept in position by the pressure of the balls passing through the caps hydraulic pressure is applied by means of the ram (*g*); if in any way the pressure becomes greater than that exercised by the ram, the latter gives way, allows the rollers to move and relieves the pressure. The plant consists of a small hand pump (*a*) by means of which a fluid, generally oil, is pumped through the pipe *ee* into the upright hollow rod *d*. Through *d* runs a channel about one quarter of an inch in diameter, communicating by a small aperture with the cylinder *b*; *cc* are weights which rest on the flange *k*; as the pressure in the oil increases it raises these weights and the pressure throughout the system is that due to the weights; the pipe *e* is continued through the cap *f*, the oil filling the hollow space enclosed between the cap *f* and the ram *g*; by a well-known principle of hydraulics if the area of the cross section of the ram is (A) and that of the fluid in the accumulator is (B) the pressure required to move the ram is $\frac{AX}{B}$ where *x* is the sum total of the weights *cc*.

When this system was first brought out the pressure applied was generally three tons per linear inch of roller, so that a roller sixty inches long had a pressure on the journals of 180 tons; to obtain this pressure the weights *cc* would be about two tons but now pressures of four, five, and even six tons per linear inch are not unusual. Besides exerting a uniform pressure this arrangement acts as a safety valve to the mill; it can be applied to top, front or back rollers, to any two or to all three; as it is only between the top and back rollers that the maximum pressure occurs, it is to one of these only that it is applied, there being no advantage in arranging the hydraulic pressure to act on both rollers. A diagrammatic sketch illustrative of the action of a "Pusher" is shown in *Fig. 35*; it is an apparatus designed to automatically force megass into a second or third mill and at the same time to ensure an even and regular feed. It consists essentially of a strong iron bar extending the length of the roller to which a to-and-fro motion is given by means of a spur and pinion and lever gear worked off the gearing of the cane engine; the rocking bar moves below the feeding table and above the front lower roller, and forces the megass into the mill by impact. In *Fig. 35* *a* represents a spur wheel six feet in diameter worked off the shaft of the second motion pinion of the cane engine; this wheel gears with a pinion *b* ten inches in diameter; the pinion carries on one side a flange *c*, twenty inches in diameter; attached to

the flange by means of a pin is a strong bar *d* which works the piece *e* to which is communicated a backwards and forwards movement in an arc of a circle; to *e* is attached a bar *f* running parallel to the rollers; *f* carries, placed at either end of the roller, pieces similar to *e* and to these is attached the pusher which forces the megass to the rollers. The pinion makes about seventy revolutions per minute and this is consequently the number of strokes given by the pusher.

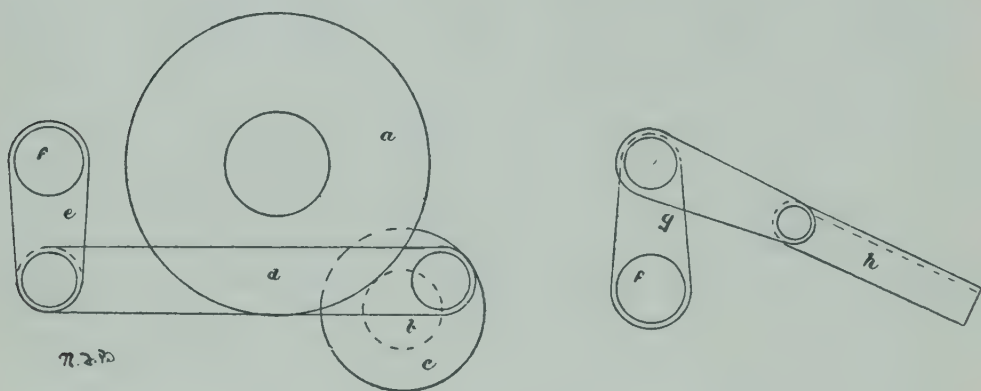


FIG. 35.

The toggle gear, *Fig. 36*, introduced and patented by the Mirrlees Watson Company, consists essentially of a combination of springs and knuckle or toggle levers, the tops of which press against the nuts of the cover bolts and the bottoms against the caps of the roller journals; under normal conditions the rollers rest on their bearings but under very heavy pressures, they lift the caps which are controlled by the toggle gear until the upward pressure is balanced. It is claimed for this contrivance that it is less expensive than a hydraulic regulator and that it performs the same duties; as in the hydraulic, the pressure can be regulated in this case by adjusting the nuts that compress the springs.

As adjuncts to crushing mills the apparatuses known as cutters, shredders, defibrators, have recently come largely into use; their object is not so much to extract juice as to prepare the canes for the mills, as by so doing the capacity of the mill is increased. They are often installed for this purpose alone; it does not seem probable that where already a powerful nine roller set is installed the extraction of juice is largely increased, but their action promotes more regular work and tends to prevent choking in the mill. Some of these devices are described below. The *Krajewski-Pesant* crusher consists of two superimposed rollers; each roller is grooved at equal distances over

all its surface in such a way as to form a succession of V-shaped teeth, the teeth in one roller being opposite the recesses in the other. The cross section through the grooving is also V-shaped. The rollers in this contrivance can be placed at varying distances so as either to crush the cane or to even cut it into pieces about four inches in length.

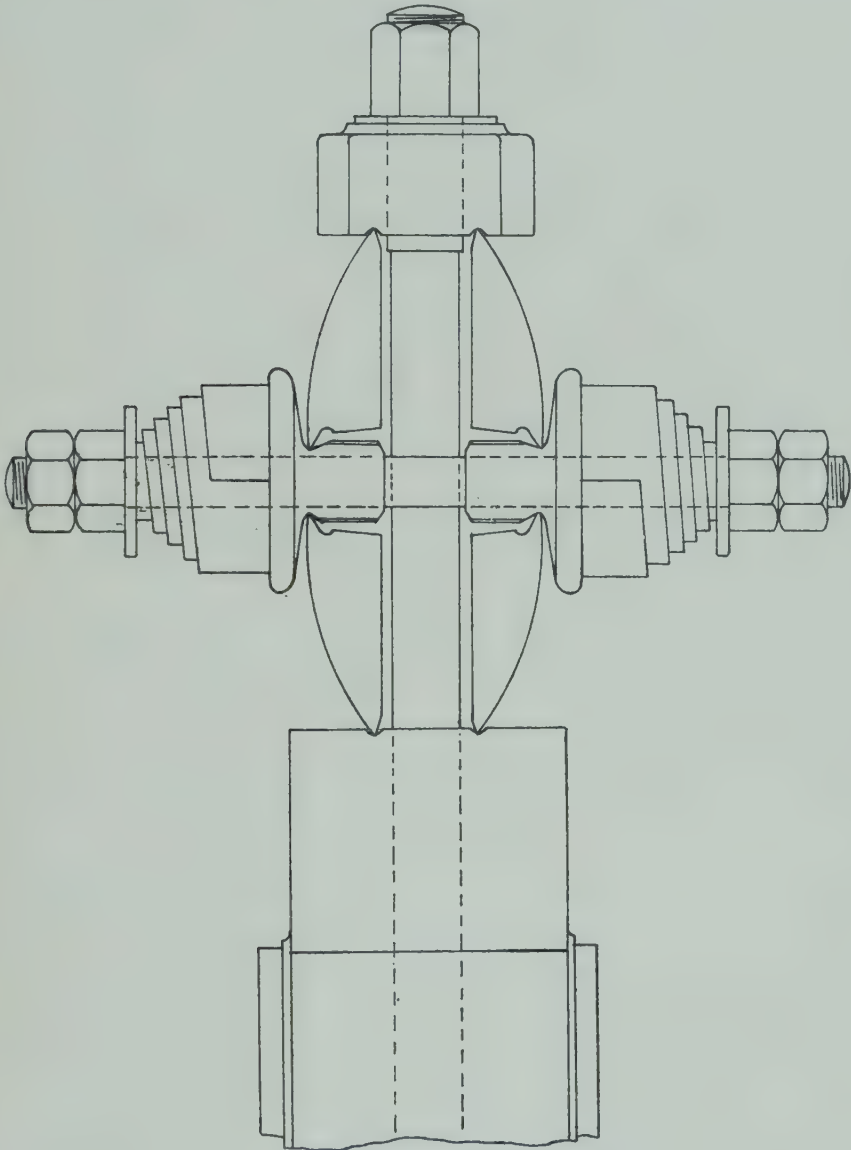


FIG. 36.

The usual form of cane cutter consists of a cylinder, on the periphery of which are arranged along a helix of slight slope a number of curved knives; these knives are placed about four inches apart and are about twelve inches long. The cylinder which extends the width of the carrier is mounted on bearings of ordinary shape in front of the

first mill and is usually driven by belt gearing off the mill engine at a speed of about 300 revolutions per minute.

Défibrators or cane shredders consist of two cylinders, on the surface of which are cut helixes in the direction of the length of the cylinder; these cylinders, which are worked at speeds of fifty revolutions or so per minute, rupture the cane as it passes through by twisting. No juice is extracted but the cane is, so to speak, shredded and prepared for subsequent treatment by the mills.

The following table gives approximately the capacities of various sizes for single, double, and treble crushing; in the latter case with dilution equal to 10% on weight of canes. The size given for the engine refers to that required to drive a first mill for the size in question, with steam at 60 lbs. per square inch; the second and third mills do not require so much power. Single crushing is estimated to produce megass with 35% fibre, and double and treble crushing mills up to 45% fibre.

Size of Rollers.	Diameter of Cylinder.	Stroke of Cylinder.	Tons of Cane per hour.			Gallons of Juice per hour.		
			Single crushing.	Double crushing.	Treble crushing. 10% dilution on canes.	Single crushing.	Double crushing.	Treble crushing. Dilution canes 10%.
Inches.	Inches.	Inches.						
18 × 30	9	18	3	4	5	415	615	880
20 × 36	10	20	5	6	8	690	925	1330
24 × 48	12	36	9	12	15	1240	1850	2640
30 × 60	20	48	15	20	25	2070	3075	4400
32 × 66	22	46	20	25	20	2760	3710	5280
36 × 72	24	48	28	35	42	3765	5390	7390
36 × 78	28	48	35	43	50	4850	6620	8800
42 × 84	30	60	45	55	65	6010	8470	11440

The nature of the surface of the rollers has a great effect on their capacity, and also on the quality of their crushing. It has recently been shown from results published in Java that rollers with a coarse grained rough surface have a capacity, *cæteris paribus*, nearly if not quite double that of smooth rollers. This effect can be obtained by special foundry mixtures, and may be helped by grooving the rollers; some forms of grooves drawn to full size are shown in *Fig. 37*.

By dry crushing is meant a mill extraction where the canes are crushed without the addition of water, as opposed to maceration or imbibition processes, where, after the cane has been dry crushed, water is added to the megass and a further portion of diluted juice extracted. In dry crushing it is very customary to term the weight of juice obtained per cent. on weight of cane, *the crushing*, and to compare the work of different mills on this basis; this is not a legitimate basis of comparison as the crushing is entirely dependent on the initial quantity of fibre in the cane; expressed algebraically, if f be the parts of fibre per one of cane, and juice be extracted till there are m parts of fibre per one of megass, the weight of megass per one of cane is $\frac{f}{m}$ and the weight of juice is $1 - \frac{f}{m}$. Now the fibre

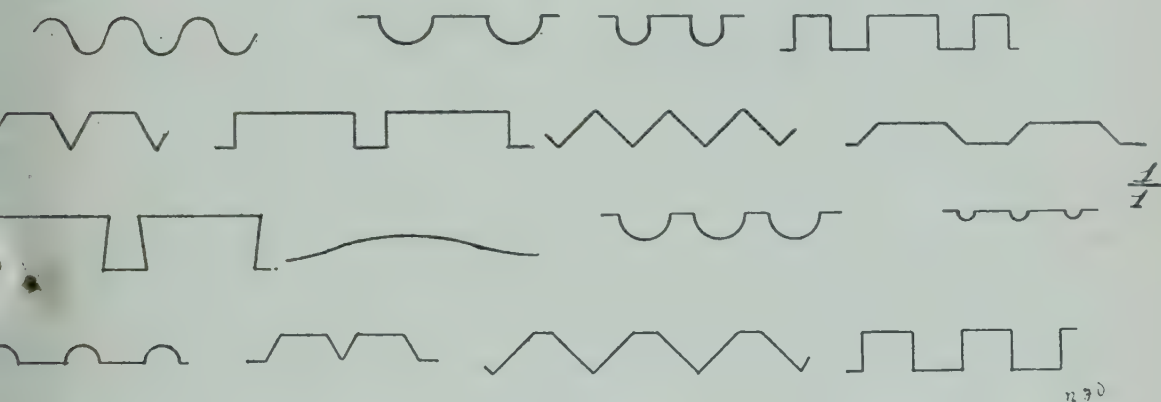


FIG. 37.

in canes varies within wide limits, it may be as low as 8% and attain in exceptional cases to as much as 16%; if the megass leaves with the same amount of fibre in two cases the crushing is equally good, but the weight of megass in extreme cases may be twice as much in one case as in another. In the table below are calculated out the weights of juice to be obtained when the canes vary in fibre content from 8% to 16% and the megass from 35% to 45%; all the figures in the horizontal line denote equally good mill work but they vary in the extreme cases, as regards quantity of juice obtained, by as much as 30%; the real test of mill work is the quantity—*volume of juice in megass per unit weight of fibre in megass*; this quantity may be expressed as

$$\frac{\text{weight of juice in unit weight of megass}}{\text{weight of fibre in unit weight of megass} \times \text{density of juice.}}$$

It is very customary to judge the quality of mill work from the percentage of moisture in the megass; this, although a much better standard than *the crushing*, may also give misleading results, as can be

FIBRE IN CANE.

Fibre in Megass.	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15	15.5	16
35	77.14	75.72	74.29	72.86	71.43	70.00	68.58	67.15	65.72	64.29	62.86	61.44	60.00	58.58	57.15	55.72	54.29
36	77.78	76.39	75.00	73.61	72.22	70.83	69.45	68.05	66.67	65.28	63.89	62.50	61.11	59.72	58.33	56.94	55.56
37	78.38	77.03	75.68	74.33	72.96	71.62	70.27	68.92	67.57	66.22	64.87	63.52	62.17	60.82	59.46	58.11	56.76
38	78.95	77.63	76.32	75.00	73.68	72.37	71.05	69.74	68.42	67.11	65.79	64.47	63.16	62.82	60.33	59.21	57.89
39	79.49	78.21	76.92	75.63	74.35	73.07	71.79	70.50	69.22	67.94	66.66	65.38	64.09	62.81	61.53	60.25	58.97
40	80.00	78.75	77.50	76.25	75.00	73.75	72.50	71.25	70.00	68.75	67.50	66.25	65.00	63.75	62.50	61.25	60.00
41	80.49	79.27	78.05	76.87	75.61	74.39	73.17	71.95	70.73	69.54	68.30	67.08	65.86	64.64	63.42	62.20	60.98
42	80.95	79.76	78.57	77.38	76.19	75.00	73.81	72.62	71.43	70.24	69.05	67.89	66.70	65.51	64.32	63.13	62.94
43	81.40	80.24	79.07	77.91	76.75	75.57	74.41	73.25	72.09	70.94	69.76	68.59	67.45	66.28	65.12	63.96	62.89
44	81.88	80.68	79.55	78.41	77.27	76.14	75.01	73.87	72.73	71.59	70.46	69.32	68.19	67.05	65.91	64.78	63.64
45	82.22	81.11	80.00	78.99	77.67	76.56	75.44	74.33	73.22	72.11	71.00	69.99	68.88	67.77	66.66	65.55	64.44

well shown by an example. In one case a sample of megass is found to contain: water 50%; sugar 8%; solids other than sugar 2%; fibre 40%; and in a second case: water 50%; sugar 4%; solids other than sugar 2%; fibre 44%. The first analysis might result from dry crushing of a good cane and the second from macerated crushing of the same or dry crushing of a poor cane; judged from water content alone the mill work is the same in both cases, but in the first case the volume of juice absorbed by unit weight of fibre is $\frac{60}{40 \times 1065} = 1.408$

and in the second case $\frac{56}{44 \times 1041} = 1.109$

the density of the residual juice in the megass being taken as 16.6° Balling and 10.7° Balling respectively. This point can be looked at in another light. Let a megass be of composition: fibre 40%, juice 60%, the juice being of density 1.065 and containing 16.6% solids and 83.4% water. The water content of the megass is then 50%. Now suppose for this juice an equal volume of juice is substituted of density 1.040 and containing 10.5% solids and 89.5% water; the crushing is evidently equally good in both cases, but now in the second case the weight of the juice is reduced from 60 to 58.6 and the weight of water increased to 52.45, which calculated on the reduced weight of megass 98.6% of the first weight gives a water content of 53.2%; at the same time the fibre content varies and for the example quoted is increased from 40% to 40.5%, a much smaller variation. The calculation of volume of juice per unit weight of fibre is not convenient and in its place the fibre content may only be substituted as being a pure criterion of mill work. A fibre content of 45% denotes excellent work, such as is obtained with modern plants.

The very serious effect of allowing dry trash to pass through the mill can be referred to here and is best shown by an actual example. Let 100 parts of clean cane carrying 12% fibre be crushed to a fibre content in megass of 45%, we then obtain 73.22 parts of juice; now to the 100 parts of clean cane let there be added one part of dry trash so that the fibre content becomes 12.87%, and let the 101 tons of cane and trash be again crushed to a fibre content of 45%; there are now obtained 71.40 parts of juice per 100 cane, and on the 101 tons, 72.14 parts of juice, a difference, when referring to the amount of juice extracted by the mill, of 1.5%.

The first mention of maceration processes is made by Wray in his treatise on sugar, published in 1848, where he describes a plant at work in Province Wellesley; it consisted of a three-roller mill

followed by a two-roller, all being driven by one engine. Between the mills was a perforated band of wire gauze conveying the megass to the second mill; from a tank placed overhead a rain of hot water was allowed to fall on to the megass, the surplus water running off being sent to the distillery. Although maceration was thus early recognised as a practical process, it was not till many years later that its use became at all general. In 1875, to obtain a premium of 100,000 francs offered by the General Council of Guadeloupe, Duchassaing introduced a maceration plant into that island; the apparatus was very similar to the one described by Wray; the two mills were placed eighteen feet apart, and between them ran a travelling band, the underside of which dipped into a tank of hot water; a tank placed above the travelling band distributed a rain of hot water over the megass. Over the travelling band was arranged a series of beaters. The juice from the two mills could be collected separately, and if the second mill juice was greatly diluted it was returned to the megass from the first mill.

Russel's and Risien's scheme introduced into Demerara about the same time was somewhat different; the mills were placed about thirty feet apart and connected as before by a travelling band. This band ran in a closed chamber of the form of a shoot; a system of perforated piping ran along the bottom and top of the shoot by means of which water or steam were forced upon the megass; means were also here provided for treating the first and second mill juice separately.

In the Rousselot system of maceration, water is sprayed on to the megass as it leaves the first or second mill, and no bath is employed; the water is conducted across the jaws of the mill by means of a perforated pipe; this system is often referred to as imbibition, as opposed to the use of baths to which the term maceration is applied.

In the Périchon system used at the Darieh Sanieh, in Egypt, the crushed megass is systematically washed in waggons on the way to the furnaces. The same water is used nine times, the fresh megass being washed with that which has already passed over eight lots of megass; after complete lixiviation the megass is crushed for fuel. The lixiviated juice contains about 5% to 6% sugar, the normal juice containing 12%; the wash waters running to waste contain from .3% to .8%.

Perforated trash turners have also been used as a means of applying water to megass; as a method of reaching the lower layers

of megass this process is defensible, but it is objectionable as weakening a part of the mill subjected to heavy strains.

At the present time two schemes are employed in washing out sugar from megass; in the one, which is sometimes distinguished as imbibition, water preferably hot is sprayed on to the megass as it leaves one mill; in the other, known as maceration, the partly exhausted megass is drawn through a bath kept filled with diluted juice which has already been extracted. As a general rule the writer has noticed that cane that has only been once crushed is not sufficiently broken up to readily absorb added water, but that twice crushed cane readily does so. A combination of the two systems may be used, maceration between the first and second, and imbibition between the second and third mills, the last expressed diluted juice serving as the diluent after the first mill.

In conducting maceration processes the following points are of importance:—

1. The water must be evenly distributed over the megass.
2. The water must penetrate into the megass; to this end it must be under a considerable head, so as to reach the lower layers; a pipe led under the blanket of megass may be used in addition to the one throwing water on to the upper surface.
3. To enable the megass to readily absorb water, it must be finely crushed; generally first crushing megass is not fine enough to readily absorb water.
4. A greater recovery is obtained when the diluent is used in two portions; this is sometimes referred to as double maceration.
5. As the mixture of juice and water is not instantaneous, as much time as possible should elapse between two successive crushings.
6. It is not economical to allow badly crushed megass to pass the first mill on the supposition that the subsequent wet crushing makes up for the loss; it does not.
7. The whole duty of maceration depends on the completeness of the admixture.

The relative advantages of single motor and multiple motor crushing plants can be discussed here. It is claimed, and, justly for the single motor plants that they are economical of steam and labour, that they are under more complete control, and, as all the mills are driven by one motor, their speed relative to each other is constant. On the other hand, it is the primary object of the mills to extract as much sugar as possible, and as these single motor plants are constructed

with a very short carrier between each mill it is extremely doubtful if the admixture of added water is as complete as it may be in multiple motor plants, where the mills can be placed any distance apart. The necessity of a long bath for maceration with the last expressed juice is most pronounced with the imperfectly crushed megass from the first mill, and in the writer's experience simple imbibition here with water or juice is of very little avail. Different methods of applying maceration processes are shown diagrammatically in *Fig. 38.*

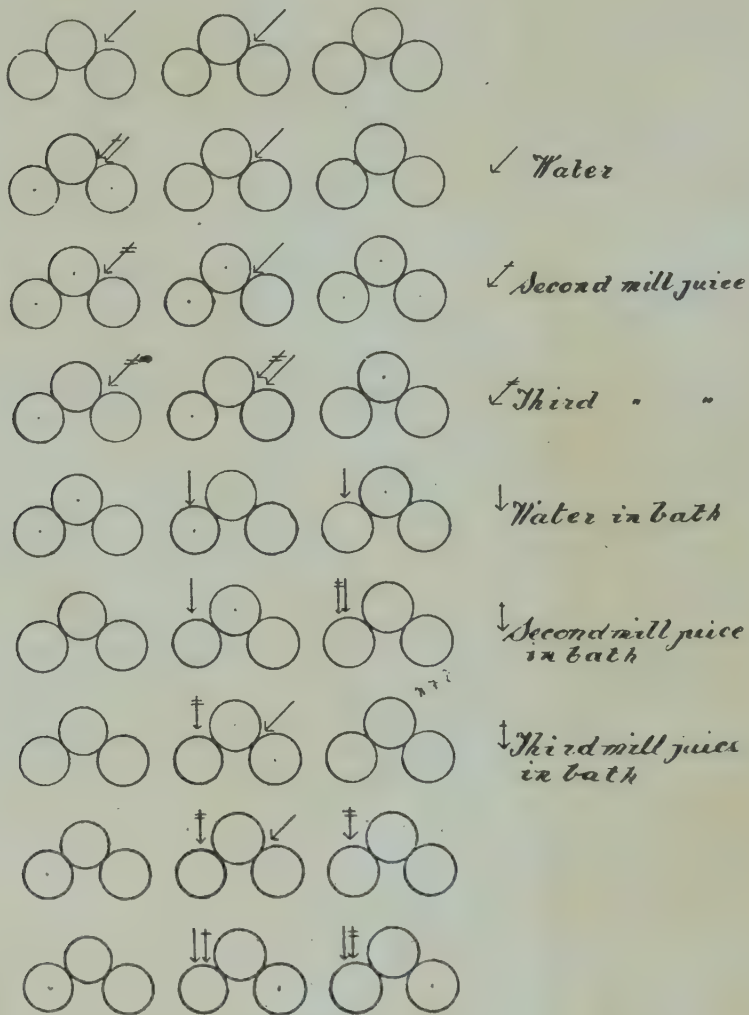


FIG. 38.

The water which is used in maceration is conveniently derived from the condensed water in juice heaters, eliminators, or effects. In the first two the water being under pressure no pump is required. If the multiple effect water be used it is convenient to pump it to elevated



FIG. 11.
PORT
MACKAY.

3
4
SIZE

tanks, and thence to allow it to gravitate to the mills. By this arrangement the water can be measured, a point of considerable importance in technical control. Very often the maceration water is derived from the hot water supply for the boilers, a pipe being led from the boiler feed pump to the mills.

Some calculations referring to the economics of mill work are given below.

Let f denote the fibre in the cane referred to the weight of cane as unity and m denote the fibre in megass referred to unit weight of megass.

Then the weight of megass compared with the weight of cane is $\frac{f}{m}$ and the weight of juice is $1 - \frac{f}{m}$.

Now since the weight of juice in the cane is $1 - f$, the sugar obtained per unit weight of sugar in the cane is $1 - \frac{f}{m} \div 1 - f$, an expression which reduces to $\frac{m - f}{m(1 - f)}$.

As an example let canes carrying 10% fibre be crushed to a fibre content of 42%:—

$$\text{Then } \frac{f}{m} = \frac{.10}{.42} = .2381 \text{ and } 1 - \frac{f}{m} = .7619$$

$$\text{and } \frac{m - f}{m(1 - f)} = \frac{.32}{.378} = .8465.$$

That is to say under the supposed conditions, 84.65% of the sugar in the cane is obtained.

Now to $\frac{f}{m}$ megass let w water be added with complete admixture and let the resulting macerated megass be again crushed to a fibre content of m . The weight of the macerated megass now is $\frac{f}{m} + w$ and the proportion of fibre is $f \div \frac{f}{m} + w = \frac{fm}{f + wm}$.

Now when this is crushed to a fibre content of m , the weight of crushed macerated megass is $\frac{fm}{f + wm} \div m = \frac{f}{f + wm}$.

The diluted juice obtained is $1 - \frac{f}{f + wm} = \frac{wm}{f + wm}$ while the whole weight of diluted juice is $1 - \frac{fm}{f + wm} = \frac{f + wm - fm}{f + wm}$.

The proportion obtained of what was left in the dry crushed megass is $\frac{wm}{f + wm} \div \frac{f + wm - fm}{f + wm} = \frac{wm}{f + wm - fm}$.

By expressing the water added in terms of the fibre the expression obtained above simplifies very considerably as shown below:—

$$\begin{array}{llll}
 \text{If } w = \cdot 1 f; \text{ the expression becomes } & \frac{\cdot 1 m}{1 - \cdot 9 m} \\
 w = \cdot 2 f; & \text{,,} & \text{,,} & \frac{\cdot 2 m}{1 - \cdot 8 m} \\
 w = \cdot 3 f; & \text{,,} & \text{,,} & \frac{\cdot 3 m}{1 - \cdot 7 m} \text{ etc.} \\
 w = f; & \text{,,} & \text{,,} & m.
 \end{array}$$

In the last case, when $w = f$, the expression put into words reads:—When the added water is the same as the fibre, the proportion of sugar extracted from that remaining in the megass is the same as the fibre content of the final megass.

As an example, taking canes of the composition assumed above, to the $\cdot 2381$ parts of megass let $\cdot 10$ water ($w = f$) be added, and let the resulting $\cdot 3381$ parts of macerated megass be crushed to a fibre content of 42%.

The proportion of sugar remaining in the megass, the original quantity being put equal to unity, is $(1 - \cdot 8465) = \cdot 1535$, and of this 42% is recovered: $\cdot 1535 \times \cdot 42 = \cdot 0645$. The total amount of sugar now recovered in the juice is $\cdot 8465 + \cdot 0645 = \cdot 9110$, *i.e.*, canes containing 10% fibre dry crushed to a fibre content of 42%, and again crushed after the addition of 10% water to a fibre content of 42%, yield 91·10% of the sugar they contain.

As was originally pointed out by the late Mr. Francis, formerly Government analyst in British Guiana, the residual juice in megass is of considerably less sugar value than that first expressed by the mills. The following figures obtained by the writer using a small hand mill will give some idea of the relationship existing between expressed and residual juice:—

Percentage of juice expressed.		Sugar per cent. in expressed juice.		Sugar per cent. in residual juice.		One part residual equal to parts of expressed juice.
74·77	..	17·34	..	15·36	..	·885
73·69	..	17·47	..	15·20	..	·870
70·46	..	17·31	..	14·35	..	·829
65·75	..	16·43	..	12·50	..	·762
68·14	..	16·49	..	14·63	..	·887
70·63	..	16·11	..	12·74	..	·791
66·04	..	16·69	..	13·73	..	·824
70·41	..	16·07	..	13·17	..	·819
75·93	..	14·86	..	12·38	..	·833
73·82	..	13·99	..	10·73	..	·767
72·08	..	13·44	..	11·46	..	·853
69·54	..	12·88	..	10·97	..	·852
69·38	..	17·75	..	14·02	..	·789
Mean						·830

If, then, as a general average the residual juice be taken as in value $\cdot 83$ of the first expressed juice, canes crushed to 42% fibre with an initial fibre content of 10% really afford 87% of the sugar they contain and with 10% added water 93%, in place of the previously calculated figures of 84.65% and 91.10% respectively.

When it is possible to so do, better results are obtained when the water is added in two parts, after a first crushing and after a second; this can easily be shown by the following calculation.

Let canes carrying 10% fibre be crushed as before to 42% fibre, and to the megass let water 5% on the canes ($\cdot 5 f$) be added and again crushed to 42% fibre; we then obtain, putting the sugar left in the megass equal to unity, $\frac{\cdot 5 \times \cdot 42}{1 - \cdot 5 \times \cdot 42} = \cdot 266$.

Again adding the same quantity of water and again crushing to 42% fibre we obtain $(1 - \cdot 266) \cdot 266 = \cdot 195$.

In the whole we then obtain of what was left in the dry crushing $\cdot 266 + \cdot 195 = \cdot 461$. If all the water was added in one operation there would have been obtained as already shown $\cdot 420$ of what was left after the dry crushing.

The effect of an indifferent dry crushing is shown in the following example.

Let canes carrying as before 10% fibre be dry crushed to a fibre content of 30%; we then obtain $\cdot 6666$ juice and $\cdot 3333$ megass, the juice being 74.07% of that contained in the cane.

Now let water 10% on the canes be added, and let the macerated megass be crushed to 42% fibre, there is now obtained $\cdot 585$ of what was left in the megass after the dry crushing, that is to say $\cdot 2593 \times \cdot 585 = \cdot 1517$.

The two crushings then give $\cdot 7407 + \cdot 1517 = \cdot 8924$ of the juice originally in the cane.

By dry crushing to 42% fibre and using the same quantity of water, it has been shown that $\cdot 9110$ is obtainable.

It is not unusual to use expressed diluted juice as a macerating agent, *i.e.*, in a double crushing plant. The expressed diluted juice is systematically returned along with the added water to the macerating bath. The macerating bath is kept full, the expressed juice and water entering at one end and overflowing at the other, and the once crushed cane passing through the bath. In this way no greater

dilution is possible, but the scheme has its advantages in presenting a process for very complete admixture. When, however, three mills are employed, and the expressed diluted juice from the third mill is used as a diluent for the first mill megass, an extra yield is obtained, as shown in the following calculation:—

Let there be three mills, each capable of crushing the megass to 42% fibre, and let the cane treated be of the same composition as before, namely, 10% fibre and 90% juice; now it is apparent that canes once crushed to 42% in the first mill will yield no more juice on passing the second and third. So after passing the second mill let water 10% on the weight of canes be added. As has already been shown, diluted juice in weight 10% on the canes, and containing $\cdot 0645$ of the juice originally present, is obtained. Now let this juice be added to the megass coming from the first mill. This megass, which contains before maceration $\cdot 1535$ of the juice originally present, will now contain $\cdot 1535 + \cdot 0645 = \cdot 2180$ and of this $\cdot 42$ is obtained or $\cdot 0916$. The first mill gave $\cdot 8465$, so that the three mills give altogether $\cdot 8465 + \cdot 0916 = \cdot 9381$ of the juice contained in the cane, and making allowance for decreased sugar value of residual juice, about $\cdot 945$ is really obtained.

The points which stand out in strongest relief as the result of these calculations are, firstly, the necessity of obtaining the maximum dry expression, and, secondly, the return of the diluted juices. Probably no single mill has yet been constructed which will crush cane to the maximum. At the present time the best plants are three-mill plants, and very possibly a more economical plant would be a six-roller tandem mill as a dry crusher, followed by two three-roller ones as macerating mills,* the last expressed juice being systematically returned to the dry crushed megass.

The question of the actual profits resulting from maceration processes may well be considered here. The factors which control the financial success or otherwise of the process are:—

1. The type of crushing plant, whether two or three mills.
2. The degree of admixture of the added water.
3. The proportion of sugar extracted for market on the total brought into the juice as the result of maceration.
4. The thermal efficiency of the factory as a whole, including the

* Quadruple crushing is in actual operation in Spain.

boiler plant, the method of evaporation, triple or quadruple effect, and the general internal economy.

5. The money value of the marketed sugar.
6. The cost of coal or other fuel.
7. The fuel value of the extra sugar extracted.
8. The expenses of making, handling, transporting, &c., the extra sugar made.
9. The sugar content of the cane.
10. The cost of the increased evaporating and other plant to deal with the larger quantities of juice.

An attempt follows to unite all these factors into one expression.

Following on what has already been written, it is simply a matter of calculation to find what amount of extra sugar is extracted as the result of added water; in what follows, the following data have been adopted:—

Canes (a).—13·69% sugar, 12·00% fibre, crushed in the first mill to 30% fibre give 60% of juice, containing 16·15% sugar; crushed further in a second mill to 45% fibre give 13·33% of juice, containing 15·34% fibre. The residual megass 26·67% on the canes contains 14·67 juice per cent. on cane, the juice containing 13·40% fibre.

Canes (b).—10·26% sugar, 12·00% fibre, crushed as in the above case, give first mill juice 12·07% sugar, second mill juice 11·46% sugar, residual juice in megass 10·20% sugar.

To the megass from canes of the above composition let water be added after the second crushing, and let the megass be again crushed to the same fibre content. The amount of diluted juice obtained is evidently the same as the water added, and the amount of sugar brought into the juice can be easily calculated when the coefficient of admixture is known. In calculating the tables below a coefficient of ·85 has been adopted, and of the sugar thus brought into the juice ·85 is estimated as capable of extraction as marketable sugar. The value of this sugar is taken as £9 per ton or 1·90 cents per pound. The expenses of obtaining this sugar are ascertained on the following basis: The composition of the expressed diluted juice is calculated allowing a purity of 80; the tons of water necessary to be evaporated to concentrate this to 50° Balling, and then to masse-cuite at 95° Balling, are calculated. Coal is taken as worth £2 at the furnace mouth, and to give for use in the factory per lb. burnt 8 lbs. steam,

each 1 lb. capable of evaporating 3 lbs. in the triple and 1 lb. in the pans; for heating the extra juice each ton is regarded as requiring $\cdot 016$ ton coal. The expenses of evaporation are thus obtained. On reference to the tables below it will be seen that the expenses of evaporation are practically constant for the different types of cane and crushing when the added water is the same, and that one ton of coal will, with the data adopted, account for twenty tons added water. If w tons water be added the expenses are then $\cdot w\text{£}$ per 100 tons canes for heating and evaporation of extra juice.

The total amount of sugar washed out of the megass as the result of the maceration is calculated before the amount of marketed sugar is obtained; the sugar is valued as fuel at £1 per ton, with coal at £2 per ton, and to the values so obtained 10% is added to express the fuel value of other organic combustible removed. With the data adopted the value of the sugar, &c., as fuel is $\cdot 144$ of the sugar marketed. The other expenses, packages, handling, transport to port, &c., are estimated at 10s. per ton or $\cdot 055$ of the value of the sugar marketed; the sum total of these last two sources of expenditure is then almost exactly $\cdot 2$ of the value of the sugar marketed. The general expression then to give the value of maceration with the data adopted is: Net profit = £7·2*S* — $\cdot w\text{£}$ per 100 tons of cane, *S* being the tons of sugar marketed, and w the tons of water added.

When only two mills are used, very different results are obtained; the method of calculation employed is somewhat different. After the canes have been crushed to 30% of fibre, water is supposed to be added, and the megass crushed to 45% of fibre; the sugar obtained is calculated on the supposition of complete admixture; the excess over that obtained by simple dry crushing to the same fibre content has already been given, and 85% of this excess is taken as the extra sugar brought into the juice as the result of maceration. The other calculations are made as detailed above.

The results of these calculations just indicated are given in the appended tables, and are also expressed as curves in Figs. 39 and 40. The curve marked "gross" represents the value of the extra product obtained at £9 per ton, and the curve marked "expenses" gives the expenditure, and that marked "economic" the profits.

Three points bearing on the subject have not been included in the above calculations. Firstly, no allowance has been made for decreased purity of the juice; in the writer's experience this is not serious. Secondly, no allowance has been made for increased consumption of

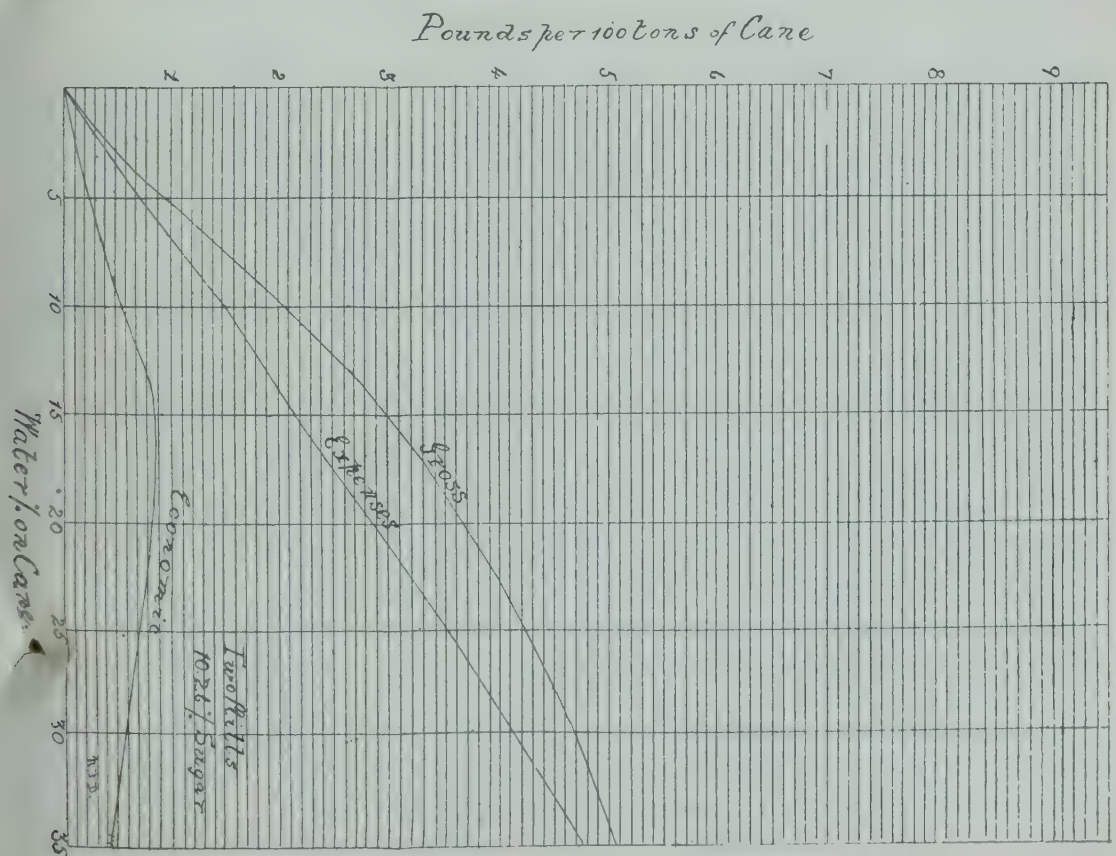
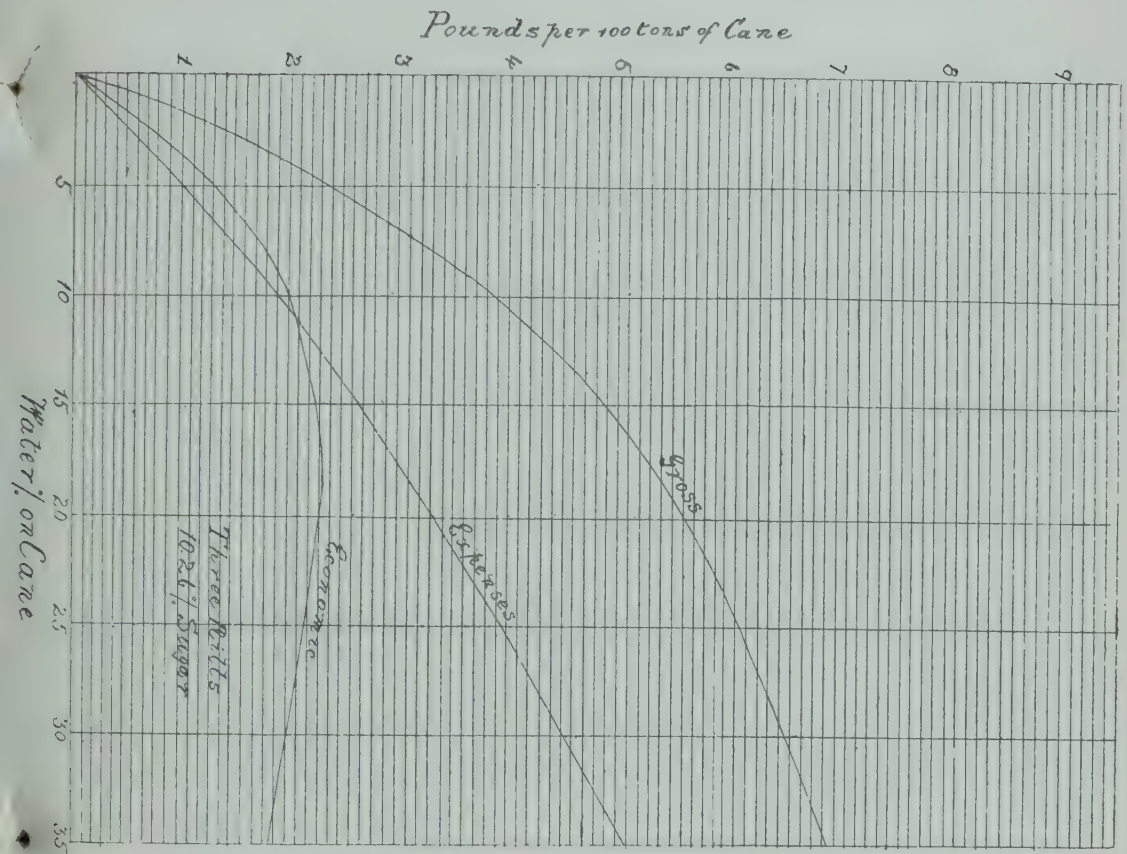


FIG. 39.

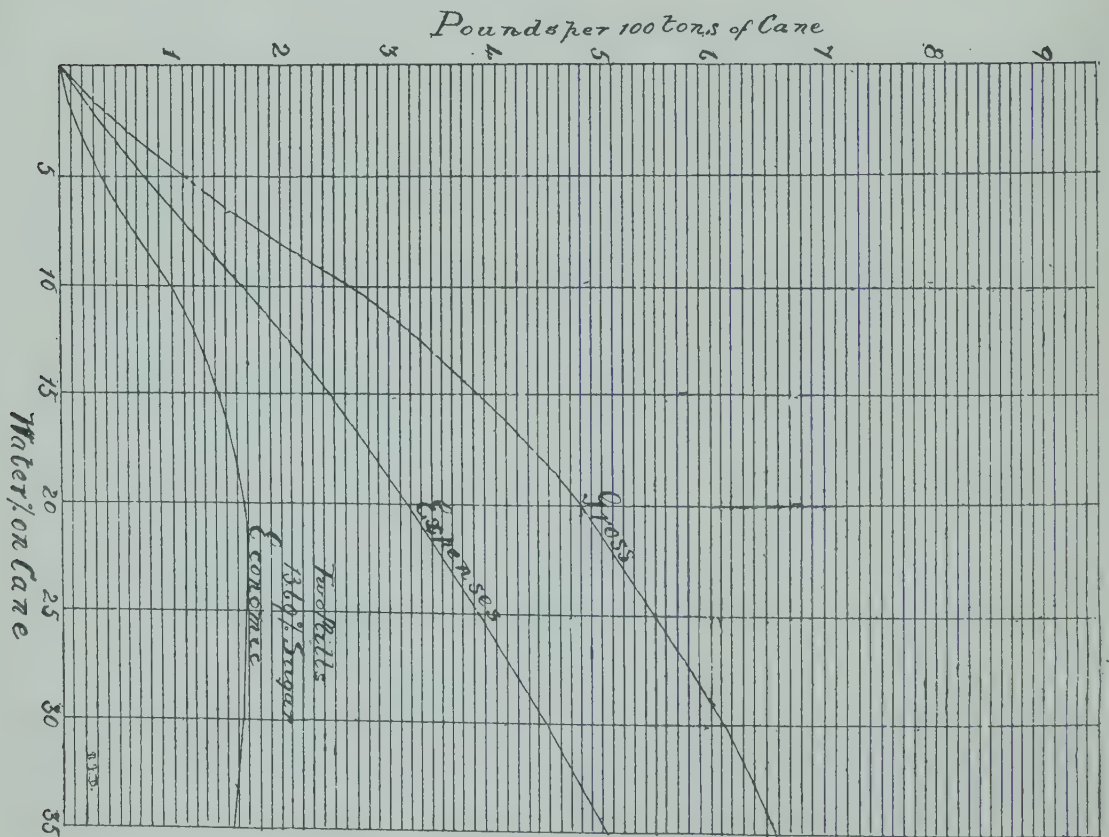
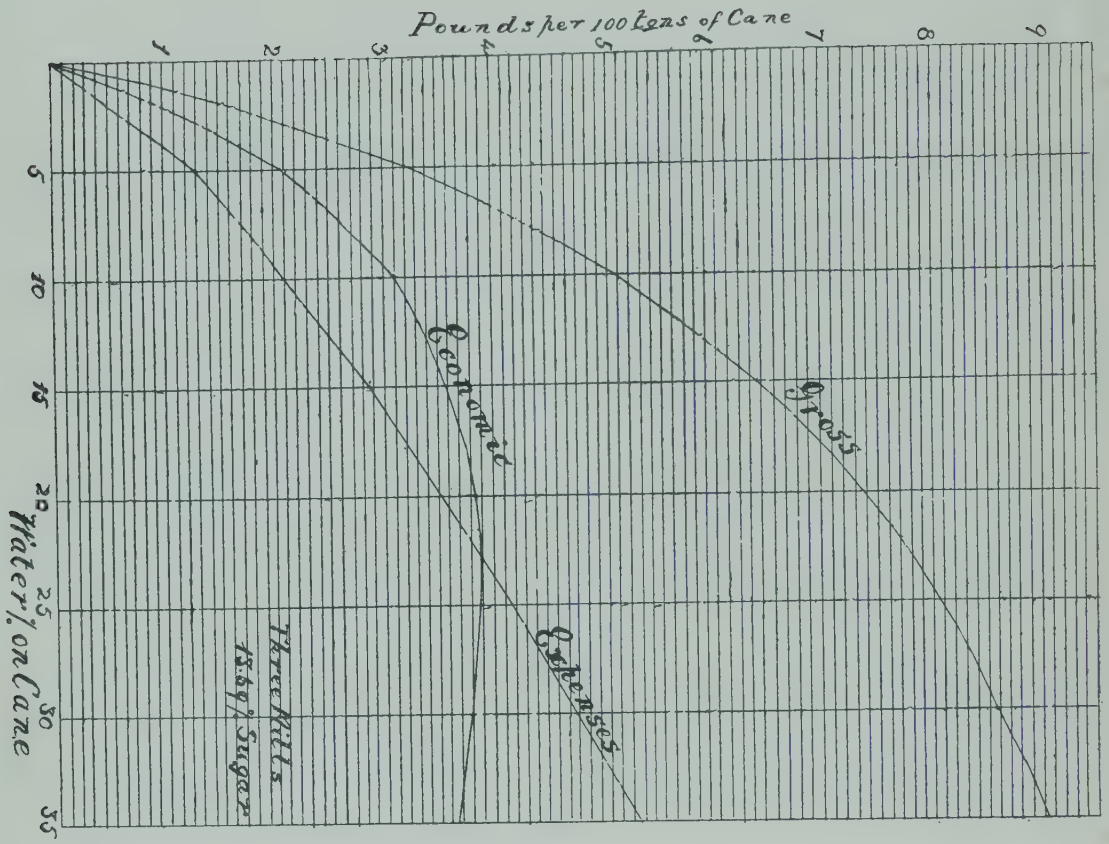


FIG. 40.

steam to drive the third mill. With a modern engine, and where the exhaust is used in evaporation, this is a small item. And, thirdly, there is the question of increased initial cost for enlarged boilers and evaporating plant. Referring to the "economic" curves it will be seen that as the curves approach the maximum, the increase in the profits is very slow. In designing a new plant, this might well indicate the financial economy of arranging for a dilution of from 5% to 10% less than the indicated maximum.

On examining the tables and curves it is at once apparent that the main factor in determining the economy is the relative value of sugar and coal; any variation from the ratio adopted here entirely alters the conditions, and an unfavourable alteration might easily, in the case of a poor cane and two mills, convert the estimated profits into a loss. The second point to be noticed is that whatever the admixture, the expenses of evaporation remain the same; a lower co-efficient than that adopted here would also, in many cases, indicate a loss. Thirdly, the great financial profit due to a third mill is clearly shown.

CANES 13·69 PER CENT. SUGAR. THREE MILLS.

Cost or Value of in £ Sterling.	Tons added Water per 100 tons of Cane.						
	5	10	15	20	25	30	35
Heating and Evaporation..	·53	1·05	1·57	2·06	2·57	3·08	3·56
Handling, Packages, Transport, &c.....	·18	·29	·36	·41	·44	·47	·50
Sugar, &c., as Fuel	·47	·74	·93	1·06	1·16	1·23	1·29
Total Expenses	1·18	2·08	2·86	3·53	4·17	4·78	5·35
Marketed Sugar	3·24	5·18	6·45	7·37	8·05	8·56	9·01
Profits	2·06	3·10	3·59	3·84	3·88	3·78	3·66

CANES 13·69 PER CENT. SUGAR. TWO MILLS.

Cost or Value of in £ Sterling.	Tons added Water per 100 tons of Cane.						
	5	10	15	20	25	30	35
Heating and Evaporation..	·51	1·04	1·55	2·06	2·55	3·07	3·54
Handling, Packages, Transport, &c.....	·06	·14	·20	·25	·29	·32	·35
Sugar, &c., as Fuel	·20	·47	·69	·84	·98	1·04	1·16
Total Expenses	·77	1·65	2·44	3·15	3·82	4·43	5·05
Marketed Sugar	1·14	2·66	3·86	4·80	5·49	6·11	6·57
Profits	·37	1·01	1·42	1·65	1·67	1·63	1·52

CANES 10·26 PER CENT. SUGAR. THREE MILLS.

Cost or Value of in £ Sterling.	Tons added Water per 100 tons of Cane.						
	5	10	15	20	25	30	35
Heating and Evaporation..	·53	1·03	1·56	2·06	2·56	3·07	3·56
Handling, Packages, Trans- port, &c.	·13	·22	·27	·31	·34	·36	·38
Sugar, &c., as Fuel	·35	·66	·83	·95	1·04	1·10	1·16
Total Expenses	1·01	1 91	2·66	3·32	3·94	4·53	5·10
Marketed Sugar.....	2·36	3·93	4·89	5·61	6·03	6·54	6·93
Profits	1·25	2·02	2·23	2·29	2·09	2·01	1·83

CANES 10·26 PER CENT. SUGAR. TWO MILLS.

Cost or Value of in £ Sterling.	Tons added Water per 100 tons of Cane.						
	5	10	15	20	25	30	35
Heating and Evaporation..	·49	·99	1·46	2·03	2·55	3·04	3·53
Handling, Packages, Trans- port, &c.	·05	·11	·16	·19	·22	·24	·27
Sugar, &c., as Fuel	·17	·42	·54	·67	·76	·85	·92
Total Expenses	·71	1·52	2·16	2·89	3·53	4·13	4·72
Marketed Sugar.....	·97	2·07	3·06	3·69	4·25	4·70	5·13
Profits	·26	·55	·90	·80	·72	·57	·41

CHAPTER X.

THE DIFFUSION PROCESS.

In the process described in the previous chapter the juice is extracted from the cane by rupture of the cells which contain the juice. In the diffusion process an entirely different system of extraction is carried out, the principle of which is as under:—If a solution of a soluble body such as sugar contained in a cell, the walls of which consist of some porous material, for example, unglazed earthenware, parchment, or the woody cells of which plants are built up, be immersed in a vessel of water, it is found that the sugar solution passes out through the porous wall into the water and that water enters the cell; this process continues until the solution on both sides of the cell is the same. It is not all bodies that possess this property. Those which do not, for example, gummy bodies, are termed colloids, and in general it is found that it is crystalline bodies that possess the property of passing through a porous membrane; to this phenomenon the name of osmosis or diffusion is given.

The sugar cane consists of a vast number of cells, in the interior of which the juice is contained; and the diffusion process applied to the extraction of juice consists of systematically allowing the juice in these cells to diffuse into water or diluted juice. In the diffusion process the cane is cut into fine slices about one-twentieth of an inch thick. These slices, technically called chips, are placed in vessels known as cells or diffusors, and are systematically washed until a very high degree of exhaustion is obtained. The system of working is roughly this: Suppose that there are twelve cells in use, these are all connected so that juice from one cell can be passed on to the next succeeding one; into a cell fresh chips are introduced; water that has passed over eleven sets of chips is forced into this cell, and after diffusion has taken place a charge of juice is withdrawn, and water which has passed over ten sets of chips takes its place. This process continues until water alone enters the cell. The highly diluted juice passes on in the above described routine, and the chips are discharged to be, in general, crushed in a mill to remove water before use as fuel.

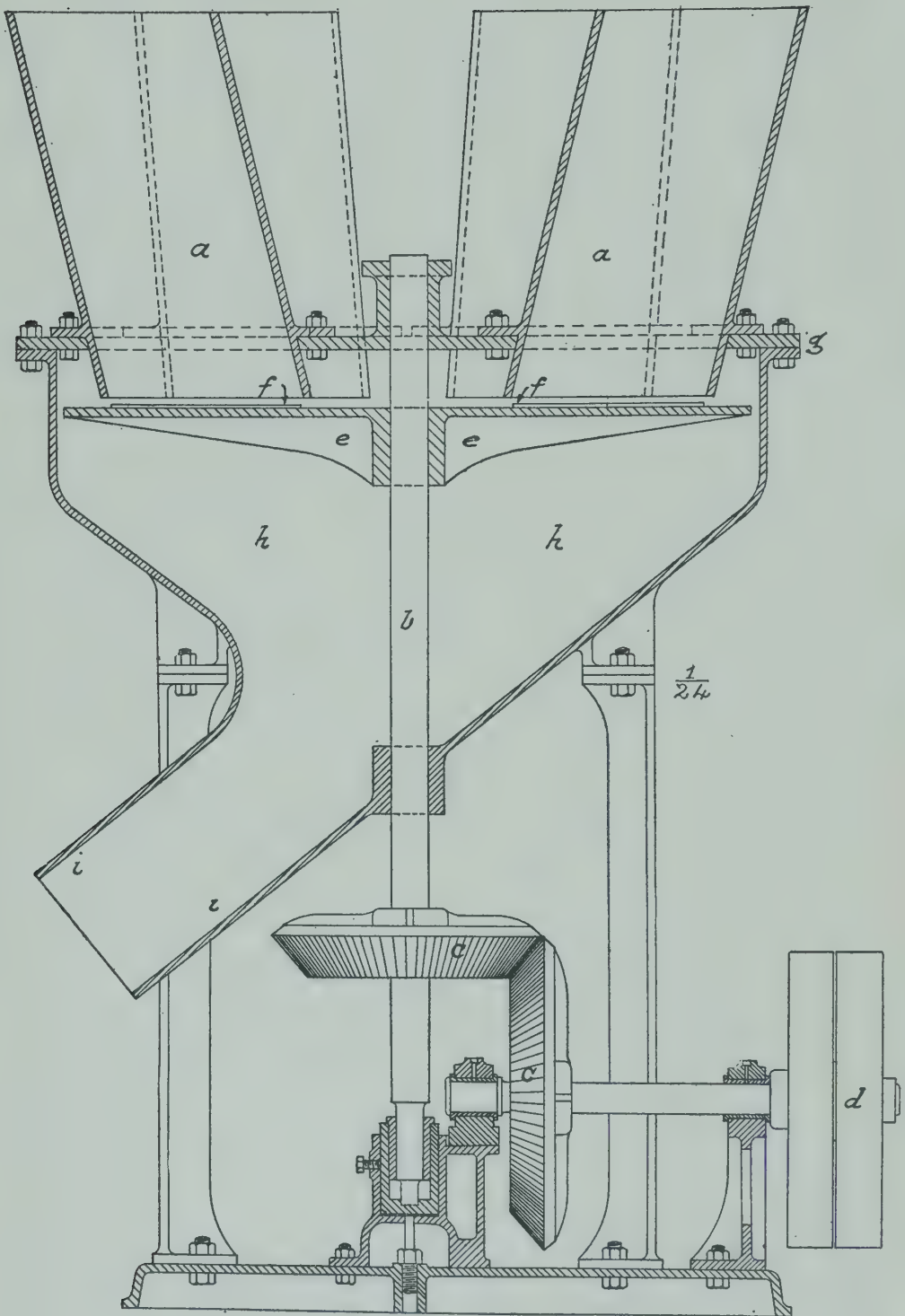


FIG. 41.

The plant necessary for the diffusion process consists of the cane cutter, the hoisting or elevating gear, and the diffusion battery, consisting of from twelve to sixteen cells, to which are attached the heaters.

A type of cane cutter that has been largely used is shown in vertical section in *Fig. 41*; on a vertical spindle (*b*), belt driven from the pulley (*d*), by means of the bevel wheels (*c*), is carried a disc (*e*). The whole is enclosed in a sheet iron casing (*h*) and closed by a strong cover (*g*); fastened on to the disc (*e*) are a number of boxes

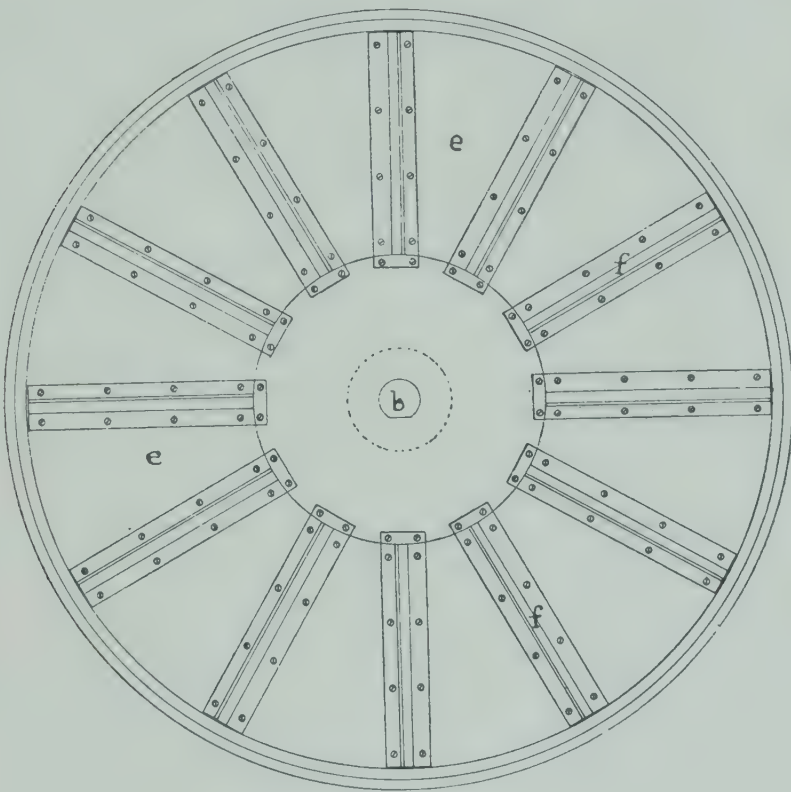


FIG. 42.

varying from six to twelve, each of which carries a strong sharp knife. The knives are fixed on the disc exactly similar to the cutting edge of a carpenter's plane, and the knife boxes are arranged so that they may readily be removed from the disc and spare knives substituted when one set has become blunted. A plan of the disc with an arrangement of twelve knives is shown in *Fig. 42*. Securely fixed to the cover are one, two or more hoppers (*a*) into which are fed the canes, which descend on to the disc by their own weight. A high speed is given to the disc, from 100 to 150 revolutions per minute,

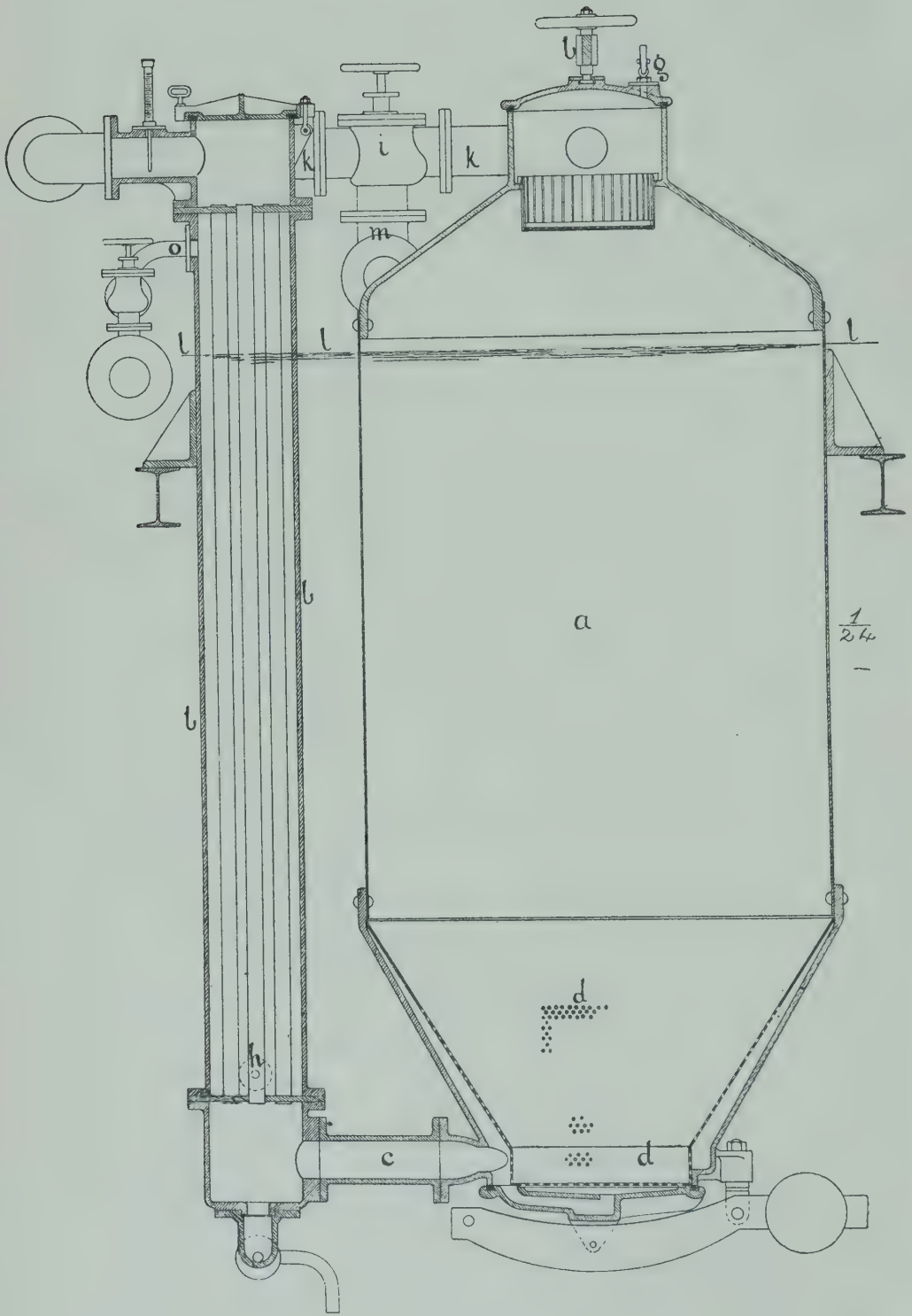


FIG. 43.

and the knives cut the cane into chips one-twentieth of an inch or more in thickness, dependent on the setting of the knives. The hoppers are made either vertical or at an angle—the former giving round and the latter oval chips. The chips fall into the receptacle formed by the sides of the apparatus below the disc, and thence pass on to the shoot. The cutter is variably placed above or below the diffusion battery. Cane cutters of this type differ in details. They are sometimes directly driven without the interposition of belt gearing, and are also sometimes over instead of under-driven, as shown in *Fig. 41*. The shoot (*i*) is also sometimes dispensed with and its place taken by a scraper actuated by the shaft (*b*). In this case the bottom of the receptacle (*h*) is flat, or nearly so, and the chips are swept out through an opening in the bottom.

To work up three hundred tons of cane in twenty-four hours, a plant of this nature will be about five feet in diameter. The capacity depends on the number of hoppers, and on the setting of the knives, whether to give thick or thin chips. More cane can be cut when thick chips are allowed, but the efficiency of the after process of diffusion is diminished. A section through a cell of a diffusion battery, along with its accompanying juice heater is shown in *Fig. 43*; it consists of a cylindrical vertical shell, the bottom being made with a slight slope, and the top fitted with a head box; the cell is closed by a door on the top, which is clamped tight by the screw and lever shown at *b*; by slackening the screw the door can be slung on one side, to allow of a charge of chips being introduced. Round the bottom part of the cell is fixed a perforated false bottom *d*, the object of which is to prevent pieces of cane being carried along the pipe *c*. In some designs the lower door itself carries the false bottom. The joint in the lower door is a hydraulic one, consisting of a hollow rubber tube provided with a pipe by means of which water is conducted to the tube, which is placed in a circular groove contrived either in the door itself or in the bottom of the cell. The water which fills this tube is taken from a tank at a high level, so that in all cases the pressure in the tube is greater than the pressure in the cell. In other cases the rubber tube is connected by a pipe with the main steam; the direct steam becomes condensed in the coil, and pressure is made in the rubber tube by the steam acting on the condensed water.

Attached to each cell or dipper is the juice heater *b*; this is of the vertical tube type, exhaust steam is admitted at *o*, and the condensed

water drawn off at *p*. Communication between diffuser and juice heater may be made either at top or bottom by the pipes *k* or *c*. The main juice circulating pipe is shown at *m*, the controlling valves or cocks appearing at *i*. The floor level on which the operator stands is at the line *l*, all valves and cocks being within easy reach; *g* is a small pipe let into the cover of the diffuser to act as an air vent to allow the air to escape when the diffuser is being filled.

The other adjuncts of the diffusion battery which remain to be described are the elevator and charging apparatus; these are very varied in design and arrangement. In case the canes are sliced on the basement, they are elevated to a floor above the level of the battery by means of an endless scraper carrier similar to those employed to convey megass to the boilers; in other cases, the cane cutting machine is placed above the level of the diffusion battery, and the canes are elevated as such, and the sliced cane distributed directly from the cutting machines.

The method by means of which the cells are filled with chips varies with the arrangement of the battery; the latter may be arranged either as a circular or as a line battery. In the former case the cutter is placed about twenty feet above the level of the top of the cells and directly over the centre of the battery, or in case the canes are cut on the basement the chips are elevated to a hopper similarly placed. The hopper or cane cutter is mounted on rollers, so that it can be revolved through a complete circle. The hopper terminates in a shoot, the discharge of which can thus be brought over any cell at will. When the cells are placed in line, the chips cut on the basement are delivered into a truck running on an overhead line, from which pass shoots directing the chips to the diffusers. Line batteries are generally placed in two parallel rows, between which is the platform on which the attendants stand.

The water requisite for the diffusion process is contained in an overhead tank, placed considerably above the level of the diffusers. The circulation of juice throughout the battery is secured by means of the hydrostatic pressure obtained from the head of water in this tank. When it is desired to empty a cell of its liquid contents, this hydrostatic pressure cannot of course be used, and an air compressor, in nearly all cases, forms a part of the plant. The latter is used also in starting the first round of the battery, and afterwards in the regular routine when a cell contains exhausted chips.

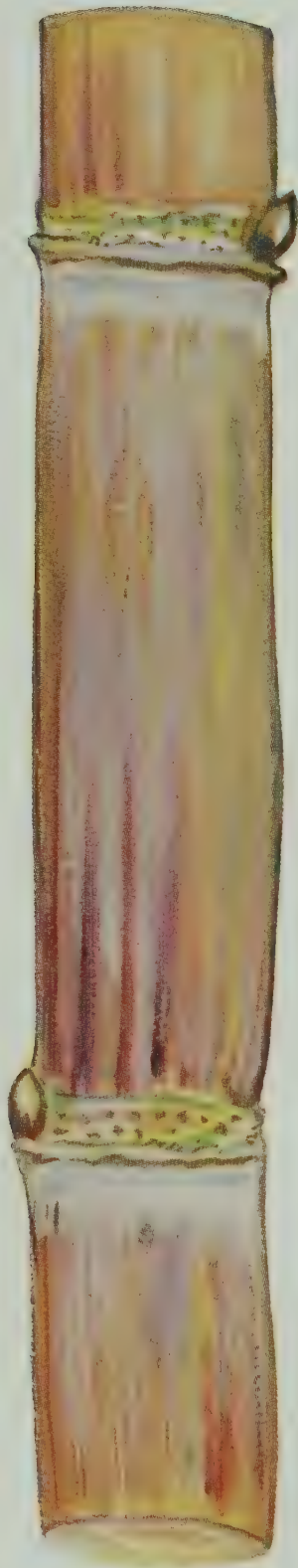


FIG. 12.
ROSE
BAMBOO.

3
4
SIZE

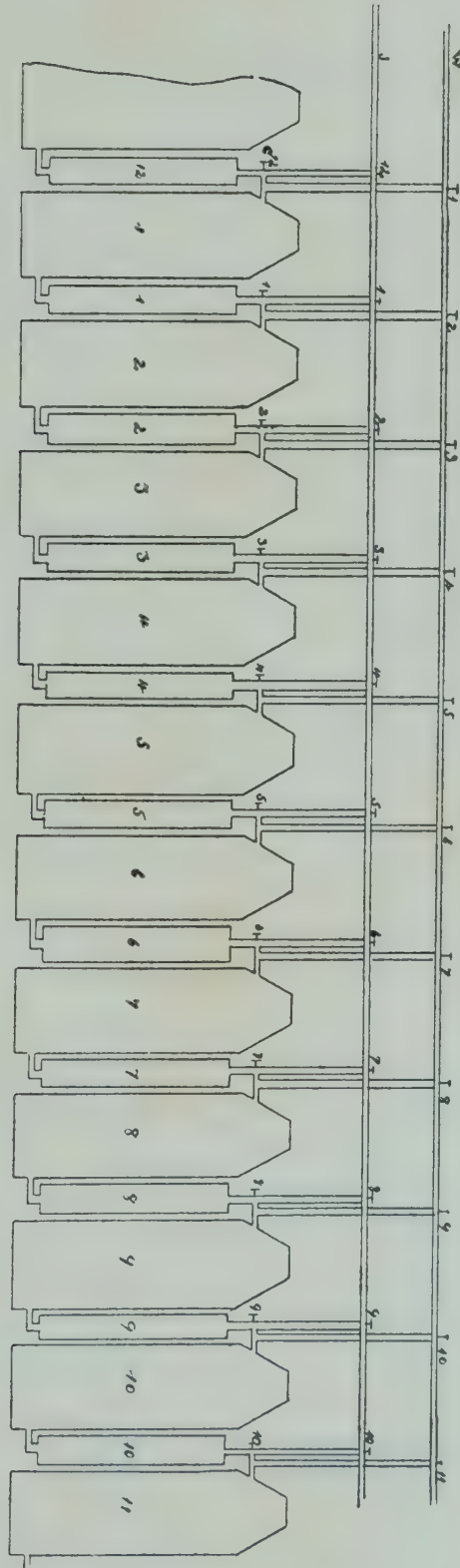


FIG. 41.

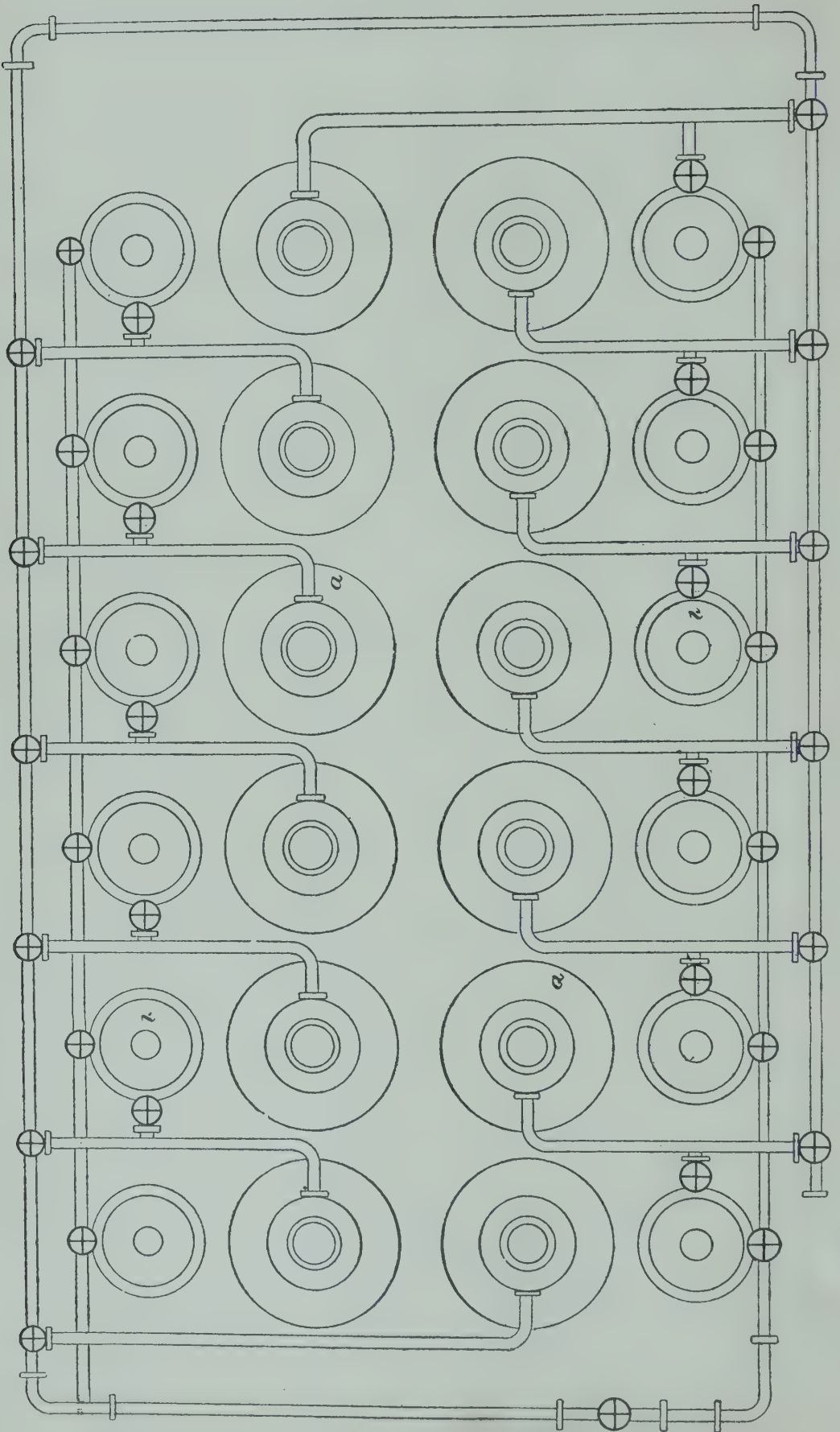


FIG. 45.

The remaining adjunct is the measuring tank. It is important in the work to draw a controllable charge of liquor. To this end the juice drawn is always measured. In many beet-sugar houses automatic self-registering weighing machines are used.

In *Fig. 45* is given a plan of a twelve-cell line battery, arranged in two rows, showing the pipe connections between cells and heaters, and in *Fig. 44* a diagrammatic sketch of a battery intended to illustrate the method of working. Let the battery consist of twelve elements which may be arranged as a line or circular battery. The pipe line W represents the water main connected to the overhead tank, and that marked J the juice main. Let it be cell No. 1 that is the first to be filled with chips; the three or four last cells of the battery are first filled with water. To do this the cock W9 is opened, and water flows into cell No. 9. When No. 9 is three parts full the top door is closed, and as soon as water escapes through the air vent the valve W9 is closed. No. 10 is now filled, but in a different way; the valves J9 and J10 are opened and also W9. Water then flows from cell No. 9 up juice heater No. 9, through the valves in the juice main J9 and J10, down juice heater No. 10 and up into diffuser No. 10. It will be seen that water passes through two juice heaters and enters the cell from the bottom; in this way the air is free to escape. This method of filling a cell is termed in French *meichage*. Cells Nos. 11 and 12 are then filled in a precisely similar manner. During the passage of the water through the juice heater it is heated and enters the cells at a temperature of about 200° F.

By this time cell No. 1 will have been filled with chips, and is now ready to receive hot water from cell No. 12. The water is passed into cell No. 1 in the manner described as *meichage*, as soon as juice passes out through the air vent. The direction of the flow of water is reversed by closing the valve J12 and opening the circulation valve C12, so that the flow is now from top to bottom.

In the meantime, cell No. 2 has been filled with chips, and the operations described in connection with cell No. 1 are carried out in a precisely similar manner. When five or six cells have been filled with chips in this way, those that were at first filled with water are emptied. To do this, the hydrostatic pressure is replaced by air pressure from the air compressor, the water connections being shut off. When cell No. 6 has been filled with chips and water, the first charge of juice is drawn. To do this the direction of the flow is changed in this cell from top to bottom, the circulation valve is

opened and the juice valve shut; at the same time the valve connecting the juice main to the measuring tank is opened. The juice from cell No. 6 will flow along the juice main under either the influence of hydrostatic pressure from the overhead tank or air pressure from the air compressor. When the proper amount of juice has been drawn the valve leading from the juice main to the measuring tank is closed, and cell No. 7 is filled by *meichage*. The chips in cell No. 1 are now exhausted, the door at the bottom is opened and the chips are discharged on to a carrier, which conveys them to a mill where they are crushed and passed on to the boiler wall for fuel.

After the first charge has been drawn from cell No. 6, a charge is drawn from cell No. 7, and so on from each cell of fresh chips until that cell is reached which was the first to be filled with chips. The first round of the battery is now complete, and the regular routine recommences. Two cells are always out of circuit, one filling and one being prepared for fresh chips. Each time a cell is filled with fresh chips a charge of juice is drawn and a cell of exhausted chips emptied.

A very important point in connection with diffusion work is the temperature to which the juice should be heated. The following temperatures are given by Llewellyn Jones as prevailing in the diffusion battery at Non Pareil in Demerara:—No. 1, 75° C.—80° C.; No. 2, 80° C.—85° C.; No. 3, 85° C.—90° C.; No. 4, 95° C.—100° C.; Nos. 5–9, 100° C.; No. 10, 90° C.; No. 11, 85° C.

At the United States Government experiment station at Magnolia during the season 1888–89 the following were the temperatures maintained:—

Cell No.	1	2–7	8–10	11	12
Temp. F.°	140	158–176	203	185	160

The temperature and densities in the different cells at Wonopringo, Java, are shown in the following table:—

Cell.	Density.	Degree Brix.	Sugar Per cent.	Purity.	Temperature °C.
Normal juice ..	1·067 ..	16·4 ..	14·55 ..	87·50 ..	—
1	1·054 ..	13·4 ..	11·66 ..	87·01 ..	69
2	1·036 ..	9·0 ..	7·53 ..	83·66 ..	77
3	1·028 ..	7·1 ..	5·95 ..	83·80 ..	92
4	1·023 ..	5·8 ..	4·64 ..	80·00 ..	91
5	1·019 ..	4·9 ..	3·88 ..	79·18 ..	89
6	1·015 ..	3·9 ..	3·09 ..	79·23 ..	88

Cell.	Density.	Degree Brix.	Sugar Per cent.	Purity.	Tempera- ture °C.
7	1·013 ..	3·4 ..	2·67 ..	78·52 ..	87·5
8	1·010 ..	2·6 ..	1·98 ..	76·15 ..	88
9	1·007 ..	1·9 ..	1·42 ..	74·73 ..	87
10	1·005 ..	1·4 ..	1·02 ..	72·85 ..	90
11	1·004 ..	1·1 ..	·85 ..	77·27 ..	92
12	1·0015 ..	·4 ..	·29 ..	72·50 ..	92
13	1·0003 ..	·15 ..	·06 ..	40·00 ..	91

It is in the cells last in series—*i.e.*, those containing the fresher chips—that the temperature should be highest; the higher the temperature the better the diffusion, and by maintaining a high temperature in the last cells, these are made to do as much work as possible.

The following notes on the quantity of juice to draw are taken from Spencer's *Handbook for Sugar Manufacturers* :—

“With a constant percentage of sucrose in the normal juice, a uniform draw and a perfectly regular extraction, the dilution and consequently the per cent. sucrose in the diffusion juice will vary considerably. This variation is due to the variable juice content of the cane. In ordinary seasons in Louisiana the per cent. juice in plant cane will average about 91, and in stubble (ratoons) about 89, consequently if we draw the same amount of juice when diffusing cane as we do with stubble, the dilution will be lower, and the analyses of the two juices will vary, even though the normal juices contain the same per cents. of sucrose. It is safe to commence working with a dilution of about 23%, estimating on an average about 90% of juice in the cane. If the extraction is satisfactory, but the density of the diffusion juice too low, the cane contains less than 90% of juice, and the draw should be reduced until a satisfactory density is obtained. With thin chips and regular work the draw may be reduced to 18%, but it is not safe to go beyond this limit, except when there is a careful chemical control to promptly detect and remedy a poor extraction. With the best multiple effect evaporation it is economical to burn more coal to evaporate additional water rather than leave two to three-tenths per cent. sugar in the chips, which might have been obtained by a little higher dilution.”

The following table, designed for preliminary work, gives the dilution for different quantities of juice drawn:—

Table showing the apparent dilution of the normal juice corresponding to different quantities of juice drawn.

(This table is based on an assumed juice content in the cane of 90%, and of an average density of 16° Brix.)

Apparent Dilution. Per cent.	Diffusion Juice Drawn per 100 lbs. Cane.			Apparent Dilution. Per cent.	Diffusion Juice Drawn per 100 lbs. Cane.		
	Weight Lbs.	Gallons.	Litres.		Weight Lbs.	Gallons.	Litres.
10 ..	99·0 ..	11·2 ..	42·3	21 ..	108·9 ..	12·4 ..	46·9
11 ..	99·9 ..	11·3 ..	42·7	22 ..	109·8 ..	12·5 ..	47·2
12 ..	100·8 ..	11·4 ..	43·1	23 ..	110·7 ..	12·6 ..	47·6
13 ..	101·7 ..	11·5 ..	43·5	24 ..	111·6 ..	12·7 ..	48·0
14 ..	102·6 ..	11·6 ..	43·8	25 ..	112·5 ..	12·8 ..	48·4
15 ..	103·5 ..	11·7 ..	44·2	26 ..	113·4 ..	12·9 ..	48·8
16 ..	104·4 ..	11·8 ..	44·6	27 ..	114·3 ..	13·0 ..	49·1
17 ..	105·3 ..	11·9 ..	45·0	28 ..	115·2 ..	13·1 ..	49·5
18 ..	106·2 ..	12·0 ..	45·3	29 ..	116·1 ..	13·2 ..	44·9
19 ..	107·1 ..	12·2 ..	46·1	30 ..	117·0 ..	13·4 ..	50·6
20 ..	108·0 ..	12·3 ..	46·5				

Before going into a comparison of diffusion work and mill work, a not unimportant difference in the composition of the resulting juice may be referred to; diffusion juice is invariably purer than the juice extracted by milling. In milling the joints of the cane and the fibrovascular bundles are ruptured and afford a juice much less pure than that given by the pith cells. In diffusion the gummy matters diffuse less quickly than the sugars, and owing to the high temperature a portion of the albuminoids are coagulated within the cell, and do not pass into subsequent processes. This point is illustrated by the following analyses from a Cuban factory working mills and diffusers simultaneously :—

	Krajewski Breaker.	First Mill.	Second Mill.	Diffusion.
Density	1·088 ..	1·080 ..	1·078 ..	1·062
Sugar, Volume %	20·43 ..	18·62 ..	17·80 ..	14·83
Glucose „ ..	·34 ..	·33 ..	·33 ..	·28
Non-sugar „ ..	2·01 ..	2·25 ..	2·54 ..	1·32
Purity	89·7 ..	87·8 ..	86·5 ..	90·3

The diffusion process as applied to the cane first came into prominence about 1884, and since then it has received extended

trials, involving great outlay of capital, in Demerara, Java, Egypt, Cuba, Hawaii, Louisiana, and Mauritius. The result of all the trials is that it has entirely failed to supplant milling processes. There are at the present moment very few factories working diffusion processes, and the majority of those that put up diffusion plant have reverted to mill extraction. The great advantage that was claimed for the diffusion process was the greater recovery of sugar; by this method from 95% to 98% of the sugar actually present in the cane is brought into the juice. This recovery is obtained at the expense of a dilution of from 25% to 30% on the weight of the cane. The highest figure claimed for a mill extraction is, the writer believes, 93.50% with added water, 21.65% on normal juice, and as a general average the majority of milling plants do not extract as much as 90% of the sugar in the cane. With so great an advantage in favour of the diffusion process it is remarkable at first sight that it has not been generally adopted. For one thing, however, the first diffusion plants erected were unsuccessful, owing to faulty design on the part of the engineering firms who erected them. The cane-cutting machines which form a very important item in the economy of the plant, were made too weak, and failed entirely to cut through the hard brittle outer rind of the cane. After a time this difficulty was overcome, as was also trouble connected with water supply, hoisting gear, and other mechanical contrivances. Afterwards, it was found that to conduct diffusion economically, a constant day and night work was necessary, and many estates which had erected diffusion plants were not in a position to maintain a continuous supply of canes; but the final cause which contributed most of all was the high expenditure in fuel. Although the amount of fibre available is in both cases the same, there is in diffusion some fuel loss, due to the greater extraction of sugar, and to the finely divided cane not being mechanically suited for combustion. But, of course, the great increase in fuel consumption in the diffusion process is due to the large extra amount of water that has to be evaporated. This point is accentuated, as much extra work is thrown on the pans where the evaporation is only done at single effect. Further, at the time most of the diffusion factories were erected, the efficiency of the furnaces and boilers was not so great as it is now in modern well-designed factories. It was quite common in diffusion factories to burn a ton of coal for every ton of sugar, and even now in such factories as have continued the process, a consumption of from six

to eight hundredweight is not uncommon. That these quantities are excessive is shown, not necessarily by calculation, but by actual experience, for it is well known that many factories working non-maceration processes, so far from not having enough megass, have great difficulty in disposing of their surplus. As an example of what should be the extra fuel required, let us suppose a factory working dry crushing has just sufficient fuel to work up the juice. Let the normal juice be 18° Brix., and from 100 tons let 70 tons juice be obtained. When working the same canes with diffusion let 112 tons juice at 13° Brix. be obtained.

Then the evaporation account will appear as under *dry crushing*. Evaporating 70 tons from 18° Brix. to 55° Brix. corresponds to removal of 47.1 tons water, which at triple effect evaporation is equivalent to (say) 16.5 tons evaporated at single effect.

Evaporating 22.9 tons from 55° Brix. to 95° Brix. entails the removal at single effect of 9.6 tons water.

The total evaporation then is referred to single effect 26.1 tons water.

Diffusion, evaporating 110 tons from 13° Brix. to 55° Brix. entails the evaporation of 81.9 tons water, which reduced to single effect work is equivalent to (say) 28.8 tons water.

Evaporating 28.1 tons from 55° Brix. to 95° Brix. entails the removal of 11.8 tons water. The total evaporation referred to single effect then is 40.6 tons water, an excess per 100 tons of cane over dry crushing of 14.5 tons water.

Now taking a ton of coal as giving nine tons of steam to evaporate the 14.5 tons of water, 1.6 tons of coal are required, and, in addition, allowance has to be made for the value of the sugar washed out by diffusion, which would otherwise have been burnt; for this particular instance about 1.5 tons sugar, equivalent to (say) 0.5 tons coal. The total fuel consumption in coal, per 100 tons of cane, over and above that necessary for dry crushing, is then 2.1 tons; 100 tons of such canes with diffusion will give at least 10.5 tons sugar, pointing to a consumption of 4 cwt. coal over that required for dry crushing per ton of sugar. The dry crushing process would have given 9.3 tons sugar per 100 tons cane, a difference in favour of diffusion of 1.2 tons of sugar to pay for 2.1 tons of coal, leaving on one side additional expenses, such as extra labour, packages, transport, &c.

This calculated coal consumption of 4 cwt. per ton sugar is much less than was found necessary in Demerara when diffusion was tried; a ton of coal to a ton of sugar was then often used.

The above comparison between dry crushing and diffusion does not altogether compare mill work with diffusion. To obtain an exact comparison the best modern mill work, three mills with double maceration, should be taken as a basis of comparison. In this case where a dilution of 10% on the weight of the cane may be estimated as bringing into the juice from 91% to 93% of the sugar, diffusion with a dilution of 20% to 25% will bring into the juice from 96% to 98%. To exactly compare the two systems is not possible. The initial expenses in capital outlay and running expenses as regards attendance, stores, oil, fuel, &c., tell against diffusion, the advantage being the not very great increased production of sugar. Perhaps the best argument in favour of mill work is that all recently erected plants have been fitted with crushing machinery.

The *Kessler* mixed process of extraction works on somewhat different lines, and has for its object the extraction of sugar from megass by a continuous process, only one diffuser being used. The apparatus may be described as an upright U-shaped continuous tube, into which megass direct from the mill is fed. Falling into this tube the megass is carried forward by a screw conveyor, forced along in a compact mass, and discharged at the other end of the tube. At one end of the tube, opposite to that at which the megass enters, water under pressure is pumped in and travels along the tube in a direction opposite to that along which the megass moves, and discharges at the end the megass enters. After the diffused megass has finally passed through the current of water, it is caught by a screw conveyor which subjects it to considerable pressure and discharges it from the apparatus. The megass after leaving the diffuser is crushed in a mill, and the highly diluted juice thus expressed returned to the diffuser.

It will be seen that this process requires at least two powerful mills—one to prepare the cane and one to dry the exhausted megass; and the best results would be obtained with two preparing mills so as to obtain the maximum dry crushing. As regards initial cost, then, a very considerable extra expenditure would be entailed as compared with mill work, but at the same time it is claimed that a practically exhausted megass is obtained with a much smaller addition of water than in the ordinary diffusion process.

The *Naudet* patent process is a combination of milling and diffusion and clarification in one operation. The canes are crushed, an extraction of 65% being all that is considered necessary. The

megass is then placed in a cell of the diffusion battery, of which there are eight or more. The juice is then heated and limed, and passed into the same cell, and filtered through its own megass and drawn off. The megass left in the cell is then treated to systematic diffusion. After being discharged from the last cell, the megass is crushed by a second mill for use as fuel.

The apparatus required, in addition to the two mills and battery of eight or more cells, is a centrifugal pump for forced filtration; two pipe mains, with suction and delivery valve connections to each cell; two straining boxes, for separating cush-cush; a compensating tank, for equalising the pressure in the cell; and two juice heaters, worked alternately.

The feature of the process, in addition to the almost complete exhaustion of the juice, is the dispensing with the usual clarifying and filtering plant:

CHAPTER XI.

THE CLARIFICATION OR DEFEICATION OF THE JUICE.

The object of clarification is to remove from the juice as far as possible all bodies other than sugar, to obtain a juice permitting of easy filtration, and working in the pans and centrifugals, and when making sugars intended for direct consumption, to obtain a bright, light coloured, transparent juice.

In rough outline, the processes in use are as below:—

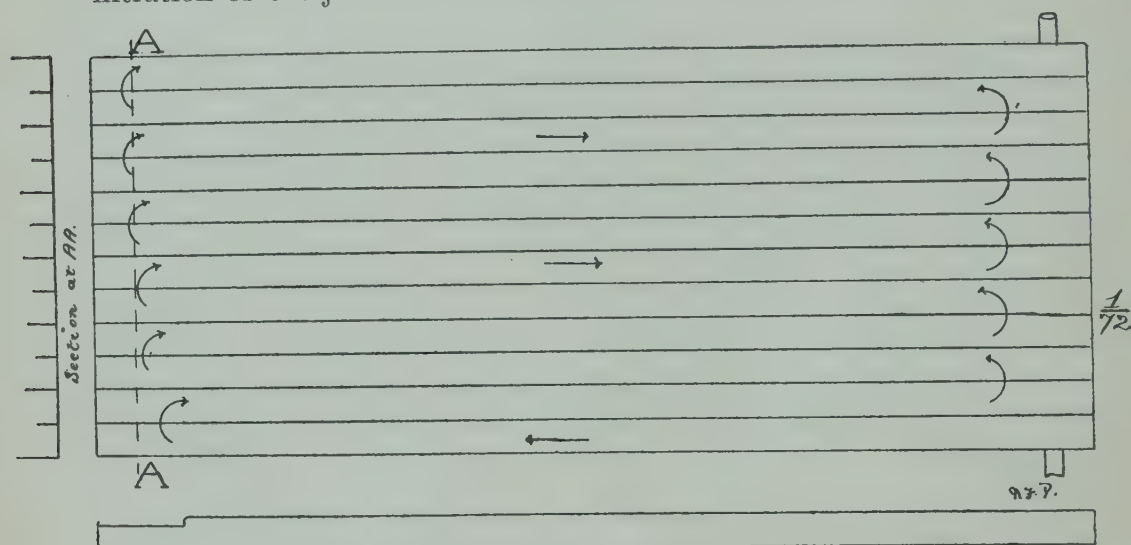
1. The juice is raised to a temperature of about 190° F. to 200° F. by being passed through a juice heater (see below); it is then received into tanks of 500 gallons capacity and upwards, where it is allowed to settle for varying times dependent upon the capacity of the clarifiers in relation to volume of juice; after half-an-hour's settling a fairly clear juice can be drawn off above a deposit of dirt and precipitated matter; this juice is sufficiently clarified to be passed direct to the evaporators when dark crystals are being made.

2. The fairly clear juice obtained as in (1.) is passed on to vessels known as eliminators; these are rectangular tanks of depth from 3 to 3½ feet, and about 8 feet by 6 feet in length and breadth; at the bottom is placed a trunnion pipe into which are fitted brass or copper tubes through which steam is passed for the purpose of heating the juice. An allowance of 1 square foot heating surface for every 3 to 4 gallons capacity is usually found. Round the top edge of the tank is arranged a gutter; the juice is boiled in these tanks with the object of bringing the suspended impurities to the surface, whence they are brushed into the gutter and passed on to the filter presses; very clear juices can be obtained by this method, which is however most wasteful of steam, (see Chapter XIII.)

3. The juice, either after passing through the juice heater, or when cold, is received into tanks provided with a heating surface similar to the one described in (2); the heating surface sometimes takes the form of a coil, or the tank may have a steam jacket. The juice is kept in these tanks at a temperature of about 205° F.; at this temperature the heavier particles of dirt subside, and a lighter aerated scum rises

to the surface; between these layers is the bulk of the juice, clear and transparent. Many factories in Mauritius make high-class, white, consumption sugars with these clarifiers alone.

4. Any of the above processes may be used, followed by a bulk filtration of the juice.



Elevation of Partition Plate

FIG. 46.

5. In Mauritius a peculiar apparatus known as a *Bac Portal* (Fig. 46) is frequently used; this consists of a shallow tank about 1 foot deep, and about 15 feet in length and breadth; the tank is divided into compartments about 1 foot wide by divisions parallel to the sides; at alternate ends of these divisions the partition is cut away to a depth of 1 inch, and to a length of 1 foot; juice being admitted to the tank at one corner fills the compartment, overflows at the far end, changes its direction, fills the next compartment, again overflows, and so on. The juice has to travel in this way a distance of about 200 feet, and during all the time it is depositing the suspended dirt. One apparatus will work continuously for twelve hours, and give a fairly bright and clear juice, but not comparable with filtered juice.

6. In Australia a continuous clarifier is in use. It consists of a cylindrical vessel about six feet high, mounted on a conical vessel also about six feet deep. The clarifier is capable of holding an hour's output of the mills, so that the dimensions become very large. The juice is introduced by a pipe which passes over the side of the vessel, and divides at the junction of the cone and cylinder into eight branches, the juice being projected against the sides of the cone. As the vessel fills there is a very slow upward movement of juice, the

dirt having time to settle. A gutter runs round the upper edge of the cylinder, into which the clear juice flows, the dirt depositing on the sides of the cone. Periodically this dirt is scraped off and the accumulated deposit discharged without interrupting the working of the apparatus.

7. In San Domingo the cold limed juice is introduced at the bottom of a double-bottomed clarifier. Within the latter is arranged a cylinder reaching to within six inches of the bottom and to within twelve inches of the clarifier. The short leg of a syphon reaching nearly to the bottom is placed within the cylinder and serves to continuously draw off the juice. The juice is kept at a temperature of $208-210^{\circ}$ F., at which temperature the scums rise to the surface and are removed without breaking them up. The temperature is kept constant by an ingenious thermostatic device: cold water circulates in a coil of copper following the curve of the bottom of the clarifier. As this water is heated it expands, and when the temperature becomes too great the expansion operates the lever of a throttle valve admitting steam to the double bottom and shuts off the supply.

The effect of a rise of temperature in the juice is to coagulate the albumen and at the same time to facilitate filtration. A juice heater, *Fig. 47*, consists of a vertical or horizontal cylindrical cast-iron body. At the upper and lower ends are placed tube plates which carry the tubes within which the juice circulates—low pressure steam enters at *a*, the condensed water is collected at *c*, the juice enters at *b*, and is caused to change its direction twice by the partition plates at *e*, passing out at *f*; at *d* are shown scum cocks for emptying the vessel after cleaning.

As a rough rule for every five gallons of juice per hour one square foot of heating surface is required.

Instead of heating the juice with back pressure steam from the engines, juice heaters are not infrequently attached as surface condensers to the last body of the multiple effect evaporator. Where a good vacuum in the last body is maintained, the juice may be heated to a maximum temperature of no more than 130° F., the further rise in temperature required being obtained by a juice heater as described above.

The action of the lime added in the process of clarification is to precipitate a portion of albuminoids, to precipitate phosphoric acid as insoluble phosphate of lime and all mineral bases except alkalies. When used in excess, lime decomposes the glucose present

in the juice. This effect is described when dealing with the carbonatation process. All the bodies precipitated by heat and lime, along with suspended dirt, fibre, and wax, are removed in the filtration.

The lime is usually applied as a cream standing about 20° - 25° Balling, the quantity required being determined by one of three methods:—

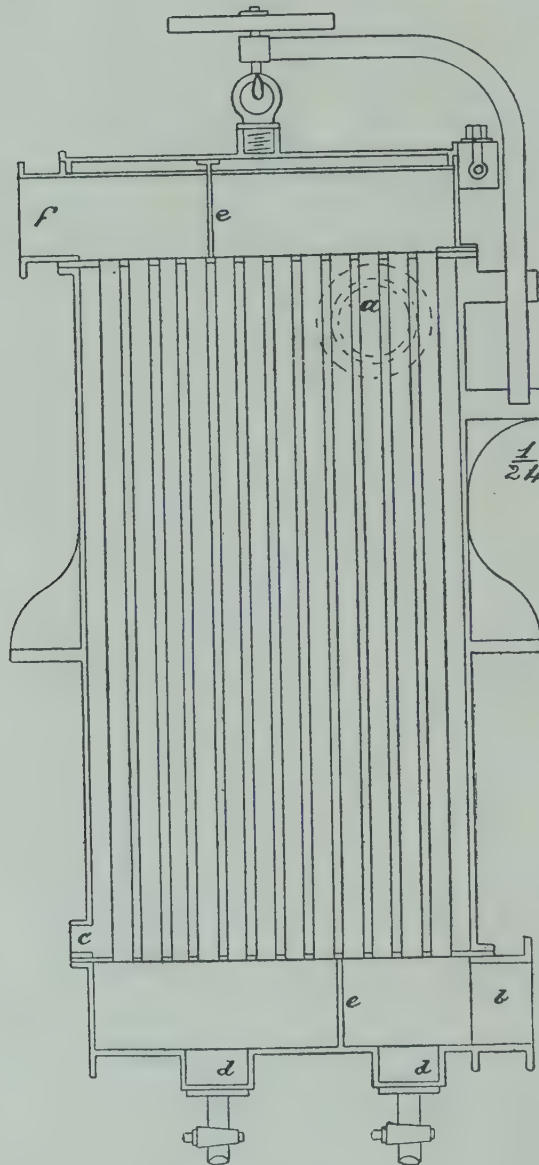


FIG. 47.

1. The raw juice is tested in the laboratory, and from the result the amount of lime required per clarifier is obtained. When working on these lines frequent tests should be made.

2. To a clarifier half full of juice an amount of lime approximately that which experience has shown to be necessary is added, and the reaction of the limed juice to litmus paper observed. According to the reaction the same, more or less, lime is added when the clarifier is full. Working in this way the proper amount of lime required for a clarifier is soon found.

3. Instead of using litmus paper, the limed juice is filtered into a test tube, and to the clear filtrate a drop of a solution of lime in sugar is added. The formation of a precipitate indicates the necessity for more lime, no precipitate occurring with an overlimed or exactly tempered juice.

These three methods do not give consonant results, for a juice limed so far as to be just alkaline to litmus will give a further precipitation on the addition of more lime; precipitation being only complete in the presence of a considerable excess of lime.

Phenolphthalein is often recommended as a more suitable indicator than litmus. The writer's experience is, however, that it is much less delicate, a juice giving a distinct alkaline reaction with litmus not showing alkaline with phenolphthalein. In general practice it is customary to lime to faint alkalinity as indicated by litmus. The practised eye can, however, tell a good clarification from the appearance of the juice, a rapidly settling precipitate combined with a hock coloured juice being the criterion looked for. The condition of the filter press cakes also affords a guide; soft sloppy cakes are often the result of too little lime, and possibly a very good plan would be to use just enough lime as will give well pressed hard firm cakes.

The above description of the process of clarification is applicable to the manufacture of refining crystals only. When making white or yellow direct consumption sugars a more complicated procedure, essentially involving the use of sulphur, is necessary. The juice is limed as it flows from the mill, the exact quantity of lime used being a matter of small importance, so long as sufficient to give a distinct alkaline reaction is used. To the alkaline juice sulphur dioxide is added in a way described below in quantity sufficient to exactly neutralise, or even to make very slightly acid, the juice. It is however of great importance that an alkaline juice be not heated, and the proportions of sulphur and lime must be carefully controlled, otherwise the juice will obtain a dark coloration which no amount of after correction with phosphoric acid will remove.

The “*sulphuring*” is often performed in the apparatus shown in *Fig. 48*. It consists in general of an upright vertical chamber, about twelve feet high, constructed of wood. At every foot or so horizontal

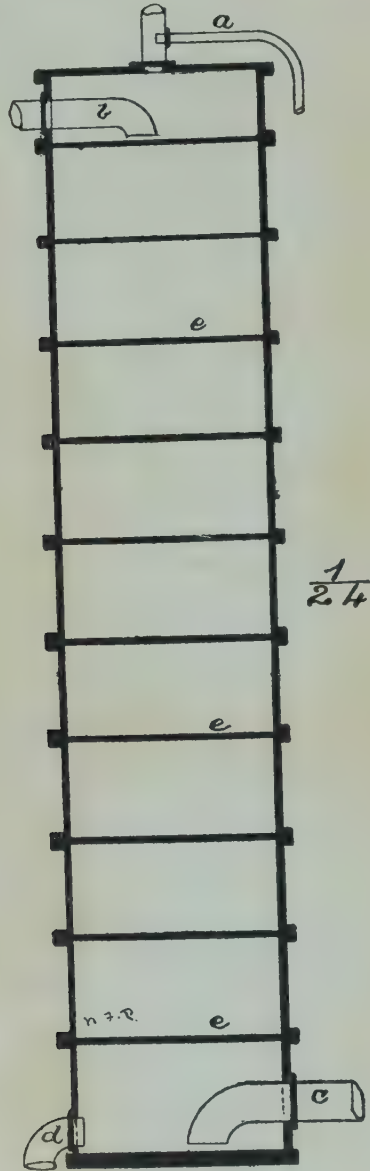


FIG. 48.

perforated plates (*e*), or some other device calculated to throw the juice into a shower, are fitted. The sulphur fumes enter the box at the bottom, being led by the pipe *c* from the oven where the sulphur is burnt. The juice enters the sulphur box at the top at *b*, and falling down in a fine shower passes out at *d*. An upward draught is created in the sulphur box by allowing a jet of steam to exhaust through the pipe *a*. This method of impregnating the



FIG. 13.
STRIPED
BAMBOO.

2
3
SIZE

uice is inferior to that employed in beet sugar houses. A view of the method there generally followed is shown in *Fig. 49*. *B* is an air compressor or pump forcing the air necessary for combustion first

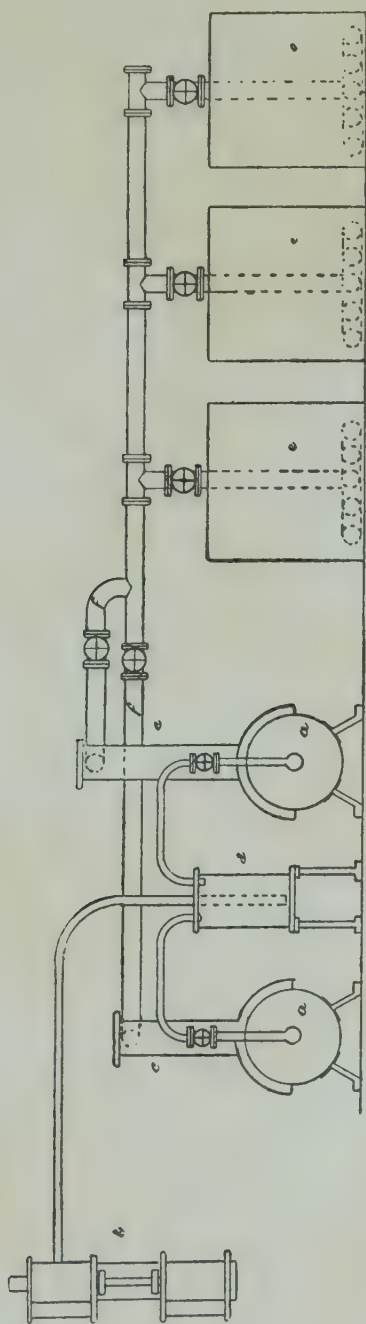


FIG. 49.

through the vessel *d*, packed with quicklime, and thence to the ovens *a*. The rate at which the sulphur burns is entirely controlled by the speed of the pump or compressor. Above *a* is a column *c*, provided with trays packed with chalk, serving to filter the gas and to retain

sulphuric acid. The upper surface of the oven is made double, so that cold water circulation may cause the condensation of sulphur volatilised. The sulphur dioxide passes along the pipe *f*, whence it reaches the bottom of the sulphitation tanks, being evenly distributed by means of a perforated coil. The ovens *a* are provided with doors, through which the sulphur is introduced, contained in a basket. So as to be continuous in action, the ovens are worked alternately.

Another method is shown in *Fig. 50*. The sulphur burnt in the oven *a* ascends through the pipe *b* under the influence of the injector

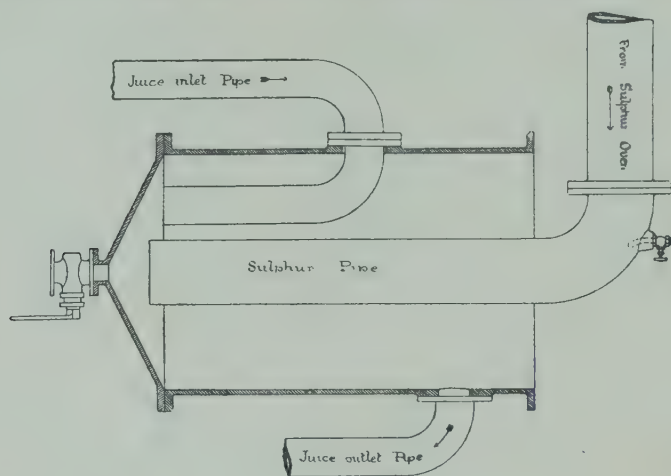


FIG. 50.

c, and enters at the bottom of the juice-containing tank. The juice flows into the tank by the pipe *d*, and overflows by way of *e*, the level of juice being about three feet.

The use of sulphur is very old. It was originally employed by Melsens in 1816, and sugar-makers are not yet agreed as to the proper place to apply this agent. Generally, it is employed on the raw juice after liming, but in some cases the lime is added to the already sulphured juice; if in both cases the juice be brought to exact neutrality, the effect is probably the same. Other sugar makers think that it is the syrup that should be treated. As here, the colouring matters are completely developed, and the sulphur being introduced at a later stage any risk of loss due to inversion is lessened.

The action of sulphurous acid on juices may be summarised:—

1. The juice is in part bleached and rendered suitable for making high-class sugars.
2. Organic salts are broken up and replaced by sulphites.

3. Juices are easier and freer to work in the pans.

4. Masse-cuites are easier to cure.

In addition, juices to which so much sulphurous acid has been added as to give an acid reaction are very bright in colour. This is an effect not due to any inherent property of the sulphurous acid, but one shared in common with all acids.

The process of liming and sulphuring does not give any greater precipitate of non-sugar matter than if the juice were limed to exact neutrality. In a laboratory experiment made by the writer juice limed to excess gave a precipitate weighing 49% on the juice. The same juice limed to excess and brought back to exact neutrality by the addition of sulphurous acid gave a precipitate weighing 35% on the juice, the same weight being obtained when the juice was limed to exact neutrality without any addition of sulphurous acid.

Although it is the object of the liming and sulphuring to obtain a perfectly neutral or perhaps faintly acid juice, a third agent, phosphoric acid, is frequently used, after the juice has been limed and sulphured. The object of this is to correct any fault in the preliminary treatment, and it is added to the juice in the vessels mentioned above as eliminators. Phosphoric acid added to a limed juice produces at first a precipitate of phosphate of lime. As the addition is continued a soluble superphosphate is formed and the precipitate dissolves. In making high-class sugars some manufacturers prefer to work with a juice just acid to a litmus paper, and others add the re-agents in such proportion that a neutral juice is obtained. According to the writer's experience, when making yellow crystals in Demerara an acid reaction is worked for; but in Mauritius, where high-grade steam-cured white sugars are made, a neutral juice is worked.

In place of using phosphoric acid, oxalic acid has been used. This body forms an insoluble compound with lime, and has the effect, when added in the proper proportions, of removing all the lime from solution. The oxalate of lime formed is not however readily removed by skimming in the eliminators, and to effect its removal the juice must be filtered *en masse*. In addition, the inverting power of oxalic acid is much greater than of phosphoric acid, and its use necessitates great care. It has never found any extended use.

The agents that have been proposed for use in clarifying are:—

1. Sulphurous acid and soluble sulphites.
2. Phosphoric acid and soluble phosphates.

3. Oxidising bodies as ozone, chlorine, hydrogen, peroxide.
4. Reducing bodies, as zinc dust in various combinations.
5. Lime, baryta, strontia and their salts.
6. Salts of the heavy metals, as zinc, tin, lead, iron, aluminium.
7. Tannin, blood, and various other organic bodies.
8. Combinations of the above designed to form a bulky precipitate, which, being allowed to settle mechanically, clears the juice.
9. Electrical processes.
10. The removal of potash and other bodies by filtration through substances containing uncombined silica.

In all, upwards of three hundred preparations have been tried, of which the use of lime, sulphur, and phosphoric acid, have alone passed into general use. The expense, or poisonous attributes, of many of the agents proposed, at once invalidates the use of many of them. On these grounds, clarification by means of lead acetate, as is done in the laboratory, is impossible on the larger economic scale. Baryta, often proposed as a substitute for lime, is expensive and poisonous, and although it gives a slightly more copious precipitate of non-sugar matter, its use as a lime substitute is impossible. Alum is often recommended to be used in conjunction with lime, so as to form a bulky precipitate in the juice, and to thus mechanically clear it. The chemical purification, *i.e.*, the removal from solution of non-sugar, is not enhanced by this process, and mechanically clear and bright juices can be obtained at less expense by filtration. A combination of alum and tannin added separately to the juice produces a copious precipitate of organic non-sugar, but to obtain a noticeable effect too large quantities of tannin have to be used. The reducing effect of zinc dust has been applied in the Ranson process, which aims at a complete discoloration of the juice by alternate oxidations and reductions. In this process hydro-sulphurous acid and hydrogen peroxide also enter. Electrical processes, which claim a complete clarification, every now and again appear, but no one of them as yet has succeeded in obtaining a firm footing. The removal of potash as a silicate is exemplified in Harm's process, where the juice (beet) is filtered through an artificial silicate made by mixing cement with Kieselguhr and ochre. A considerable proportion of the potash, together with some organic matter, is retained by the filtering medium. The process is not at all unlike the use of animal charcoal filtration.

The colour re-actions of cane juice having an important bearing on the manufacture of direct consumption sugar may be mentioned here. In the presence of an excess of alkali, filtered cane juice is of a golden yellow colour; if the alkali be gradually neutralised with an acid a point is reached where the golden yellow colour turns to an olive brown; the addition of the acid being continued the cane juice finally becomes almost colourless. When in the intermediate olive brown zone, the juice is almost exactly neutral. The colour re-actions of cane juice as described above are exemplified in the following experiment:—

To 100 c.c. of clarified almost neutral cane juice, exactly sufficient normal caustic soda was added to develop the golden yellow tint, the quantity found necessary to be added being 1 c.c. To 100 c.c. of the cane juice thus treated normal sulphuric acid was added and the changes in colour observed; the different juices were kept at a temperature of 95° C. for half-an-hour, so as to determine at what point appreciable inversion (see below) set in. The details of an experiment are given below.

100 c.c. of clarified cane juice treated with 1 c.c. normal caustic soda developed maximum yellow coloration.

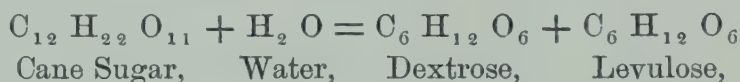
c.c. normal acid added per 100 c.c. of prepared juice.	Colour.	Re-action.	Polarisation after heating to 95° C. for half-an-hour
·0	Golden Yellow	Alkaline	58·1
·4	„	„	58·0
·8	„	„	58·1
·9	{ Intermediate olive brown zone	Neutral	58·0
1·2		„	58·0
1·4	Light	Acid	58·1
2·0	„	„	58·0
2·2	„	„	57·0
2·6	„	„	49·0

It was not until there was an excess of normal sulphuric acid of 1 c.c. per 100 c.c. of juice over and above the neutral intermediate zone that inversion was detected, and there is thus the limit which the manufacturer can allow himself when making consumption sugars without danger of inversion. The test can be easily conducted as a part of the regular routine. To 100 c.c. of the finally tempered juice, 2 c.c. of normal alkali are added, and the colour of the juice is compared with another sample to which excess of alkali

has been added. If the 2 c.c. develop the maximum coloration, there is no danger of inversion; of course it is advisable that the juice be as little acid as possible, provided that the requisite light colour be obtained.

Although not directly connected with clarification, the phenomenon known as inversion may be conveniently described here.

Cane sugar in acid solution is converted into equal quantities of dextrose and levulose, the mixture of the two being known as invert sugar, and often incorrectly referred to as glucose. The process obtains under the equation



one part of cane sugar giving 1.0526 parts of invert sugar.

This process is called inversion since the solution of cane sugar which was originally dextrorotatory, after the action of acids is laevorotatory, and hence the sugar is said to have been inverted. The term *altered sugar* is used by earlier writers.

The phenomenon of inversion, besides bearing largely on the manufacture of cane sugar, is of great theoretical interest, and hence has been largely investigated. The laws under which the phenomenon occurs are briefly—

1. The rate of inversion varies with the acid used. The coefficients of inversion of some acids are given in the table below, referring to hydrochloric acid as 100. The numbers given refer to chemically equivalent quantities, and not to equal weights. Thus, if the sugar inverted by 36.5 grams of hydrochloric acid is 100, that inverted by 45 grams of oxalic acid is 18.57, the conditions being the same.

2. The rate of inversion increases with the concentration of the acid. For concentrations of about the same value the rate of inversion is probably proportional, or very nearly so, to the concentration.

3. The rate of inversion increases with the temperature. This point has been investigated by Spohr, who found that for every rise in temperature of 10° C., between the limits 25° C. and 55° C., the amount of sugar inverted increased 3.36 times, other conditions being equal. In addition to acids, the salts of the heavy metals which possess an acid reaction are capable of inverting sugar. Such bodies

are zinc sulphate, ferric chloride; but as they do not occur in the manufacturing process, the point is not of importance.

The inversion of sugar by glucose does not take place as has been frequently stated. Sugar is, however, inverted by the combined action of glucose and neutral salts, such as potassium chloride, sodium sulphate. This action has been made the subject of a detailed study by Geerligs, whose results are given in Chapter XVII.

Besides chemical inversion under the influence of acids and salts, cane sugar is inverted by the action of certain ferments known collectively as enzymes. The most important enzyme is that secreted by yeast and known as invertase. By the action of this body, which is widely distributed in the vegetable kingdom, and which also occurs in the alimentary canal of mammals, cane sugar is rapidly inverted. The inversion of cane sugar in wash set up to ferment is due to this body. Its properties have been investigated by O'Sullivan and Thompson, who have found that the most favourable concentration of sugar solution is about 20%, that the *optimum temperature* is from 55° C. to 60° C., the enzyme being slowly destroyed at 65° C., and instantaneously at 75° C. Small traces of acid increase the invertive power, which is practically inexhaustible—the ferment itself suffering no change. This body is again referred to when dealing with sugar analysis.

TABLE GIVING THE CO-EFFICIENTS OF INVERSION OF DIFFERENT ACIDS AT 65° C.

Acid.	Co-efficient of Inversion.	Acid.	Co-efficient of Inversion.
Hydrochloric ..	100	Citric ..	1.72
Nitric ..	100	Acetic ..	.400
Sulphuric ..	53.6	Tartaric ..	Not determined, but probably similar to Citric.
Oxalic ..	18.57	— ..	
Phosphoric ..	6.21	Sulphurous ..	Not determined, but probably very small.
Malic ..	1.27	Boracic ..	
Succinic ..	.545	— ..	—

The Deming process of superheat clarification has come into extended use since its introduction in 1896. In this system the limed juice is heated by direct steam to a temperature of about 230° F. in closed vessels. The apparatus consists of three superimposed vessels which may best be described as horizontal tubular juice heaters. The tubular elements are two inches in diameter, and all the three

vessels communicate. The passage of the juice is outside the tubes of the first vessel and through the tubes of the second and third, and then back through the tubes of the first. The two first vessels are called absorbers, and the last the digester. In the second vessel exhaust and in the third live steam circulates round the tubes. The temperature of the juice in the third vessel reaches 230° F., and meeting a counter current of cold juice on its return passage through the first vessel is reduced in temperature to 200° F. The juice passes with great velocity through the tubes, and is only under treatment about two to three minutes. Owing to the high velocity of transit it is said that the tubes do not scale.

The second part of the Deming plant consists of tanks designed to effect the automatic separation of the scums. The tanks are cylindrical, the lower part being funnel shaped, at the centre of which is the discharge pipe. Inside the tank is suspended a truncated cone of sheet iron. The upper and narrower part of the cone is on a level with the top of the settling tank, and the lower wider part on a level with the top of the funnel shaped bottom of the tank. The distance between the outer edge of the cone and inside of the tank is about one inch.

The passage of juice from the superheating apparatus into the tanks is outside the cone, the tanks thus being filled from the bottoms upwards. The juice discharges through a wide pipe ending high up within the cone. The idea of the arrangement is that the scums continually sink to the bottom, and if any happen to rise, as under the influence of a local convection current, they strike against the side of the cone and are deflected downwards.

It is claimed for this apparatus that saving in space, labour and steam is effected, together with a separation of more gummy matter than in ordinary processes.

The following figures dealing with the process are due to Beeson (*Sugar Cane*, No. 330):—

Juice.	Total Solids.	Sucrose.	Solids not Sugar.	Purity.	Glucose.
Diffusion	14·9	11·22	1·69	75·3	1·99
Ordinary Clarification..	14·9	12·04	0·83	80·9	2·03
Deming Clarification . .	14·9	11·58	1·29	77·7	2·03
Diffusion	14·9	11·78	1·11	79·1	2·01
Ordinary Clarification..	14·9	11·65	1·21	78·2	2·04
Deming Clarification . .	14·9	10·85	2·06	72·8	1·99

Juice.	Glucose ratio.	Total Proteids.	Albumen- oids.	Amides.	Alcoholic Precipitate.
Diffusion	17.7 ..	.248 ..	.0617 ..	.1863 ..	.105
Ordinary Clarification..	16.9 ..	.205 ..	.0416 ..	.1634 ..	.202
Deming Clarification..	17.5 ..	.208 ..	.0434 ..	.1646 ..	.171
Diffusion	17.1 ..	.215 ..	.0733 ..	.1417 ..	.246
Ordinary Clarification..	17.5 ..	.201 ..	.0538 ..	.1472 ..	.336
Deming Clarification..	18.3 ..	.202 ..	.0447 ..	.1574 ..	.297

Edson experimenting at Calumet, Louisiana, found juices treated by the Deming process to filter more rapidly than others.

Temperature of Clarification.	215° F.	230° F.	246° F.	260° F.
Filtration started at ..	3.45 ..	3.45 ..	3.45 ..	3.45 ..
Juice freed from mud at	4.15 ..	4.05 ..	3.56 ..	3.56 ..
Time of filtration . . .	30 min. . .	20 min. . .	11 min. . .	11 min. . .
Using juice heated to 260° F. as a unit, the time of filtration was	2.75 ..	1.82 ..	1.00 ..	1.00 ..

The process was also subjected to a trial by Geerligs, in Java, the factory in question working alternately the Deming and the older process. The analyses of the juice show no difference, but the analyses of the molasses indicate that more gums were precipitated by the Deming process.

	Ash.	Lime.	Gum.	Silica.
Molasses, Cheribon cane, Defecation	4.67 ..	0.207 ..	0.808 ..	1.28
„ „ „ Deming	4.59 ..	0.245 ..	0.720 ..	1.09
„ Muntok „ Defecation	4.50 ..	0.370 ..	0.636 ..	1.32
„ „ „ Deming	4.55 ..	0.331 ..	0.604 ..	1.24

Geerligs remarks that “from a chemical point of view Deming’s superheat clarification stands in no respect behind the usual defecation process, whilst its mechanical advantages are many.”

The juices in the above-mentioned trial were very pure, and the effect of superheating on the gums did not have a fair trial. Geerligs inclines to the view that for juices of low purity the Deming process may be a convenient substitute for the expensive carbonatation one.

CHAPTER XII.

THE CARBONATATION PROCESS.

The carbonatation process, which is quite generally adopted in beet sugar factories, has only been applied to the manufacture of cane sugar in a few instances in Java and India. This process, though very successful in beet factories, gave bad results when first introduced into cane sugar factories owing to the presence of glucose in cane juice,—this body not being a constituent of sound beets. It is owing to the efforts of Geerligs and Winter in Java that the process has been made even practicable, but that it will ever be generally adopted is problematical.

The essential principle of the process is the use of a large quantity of lime in the clarification, giving a very copious precipitate of organic non-sugar, the excess of lime being removed by the passage of carbon dioxide, as an insoluble carbonate. Besides precipitating organic matter, the lime acts on the glucose, converting it into saccharic, glucinic, and lactic acids, the proportions of each being dependent on the temperature at which reaction takes place.

Two processes are distinguished, single and double carbonatation. In the single process a quantity of lime which, calculated as dry anhydrous lime, amounts to as much as 1% to 1.5% of the weight of the cane is added to the juice; carbon dioxide generated by the combustion of limestone in limekilns is pumped through the juice until the latter is neutral; the juice is all this time at a temperature of 60° C.; the temperature is now raised to 90° C., and the juice filtered; in some cases the juice is filtered *en masse*, and in others it is allowed to settle and only the scums filtered.

In the double carbonatation process the juice is limed as above at a temperature of 60° C., and carbon dioxide passed in until the alkalinity is one represented by .05% lime; the juice is then separated from the precipitate by means of filtration, raised to the boiling point, saturated with carbon dioxide, boiled for a few minutes to break up bicarbonates, and again filtered.

The chemistry of the process is thus explained by Geerligs (*Sugar Cane*, No. 334):—At temperatures near the boiling point the action of lime on glucose is to form chiefly saccharic and glucinic acids; if

the temperature however does not rise above 60° C., saccharic and lactic acids are chiefly formed, and only small quantities of glucinic acid. The glucinic acid formed combines with the lime to form an insoluble basic glucinate; this basic glucinate is insoluble in an alkaline medium at temperatures below 60° C. but redissolves with rise of temperature or on neutralisation of the free alkali. In the single process, then, the glucinate of lime, after being insoluble, again becomes soluble, and re-enters into solution; in the double process it is removed.

In addition to the action of an excess of lime on glucose, gummy and other matters are only precipitated by an excess of lime and considerably more impurities are thrown down by the excess of lime than in the ordinary process; on neutralisation these bodies redissolve, and the final effect is the same as if lime had only been added in the usual quantities. This effect takes place in the single process, and it is only by filtering the strongly alkaline solution, and by removing the lime afterwards that the full benefit of the carbonation process is obtained.

It is claimed for the carbonation process that the clarification is more complete, that it is more easily controlled, that there is no necessity to temper the juice, and that filtration is easier. The benefits of the process are most noticeable in the case of impure juices, and especially those which contain a large amount of gummy matter. High-class consumption sugars are made by the process, but in this case it is often necessary to correct the final carbonated juice with phosphoric or sulphurous acid.

On the other hand the destruction of the glucose entails a direct loss where the molasses are used to manufacture rum as a by-product, and the initial capital cost in lime-kilns, saturators, gas-washers, pumps, and extra filters is very heavy, and current expenses in fuel and labour are also increased.

When using this process the sugar content of the exhausted molasses is much higher than in molasses resulting from the ordinary process. This is due to the largely increased proportion of organic salts—saccharinates and lactates—formed from the glucose; at the same time the quantity of molasses formed is much less. This very important point is discussed in the chapter on *Molasses*.

Below are given details of analyses (by Geerligs) of juices treated by the carbonation process; analyses of the scums are given in the succeeding chapter.

	Brix.	Sugar. Per cent.	Glucose. Per cent.	Purity.	Glucose ratio.	Pectine. Per cent.
Mill juice.. . . .	18.4	15.72	0.92	85.6	5.9	0.634
Clarified by defecation ..	18.6	15.99	0.95	86.1	5.9	0.292
Clarified by carbonatation	16.9	14.65	0.44	86.7	3.0	0.142

It remains to describe the practice of the process, which may be varied in details to suit the requirements of different factories or the ideas of different manufacturers. In the single process, the juice is received as usual in tanks, where it is treated with from 10 % to 20 % of milk of lime, standing at 20° Balling. Attempts made to introduce the lime in a dry state have not been successful, but to prevent the considerable dilution that would be necessary if the lime were mixed with water, the dilute washings from the filter presses are substituted. The carbonatation may be performed in the vessels in which the juice is received, or the limed juice may be run off into special tanks; the exact amount of lime added not being a matter of importance, the use of liming tanks is not essential.

In the double process, the first carbonatation is performed in the vessels in which the lime is added, after which the juice is filtered *en masse* or else decanted and the scums only filtered. The cleared first carbonatation juice is then passed on to the saturation or second carbonatation tanks where the process is finished as already indicated.

It is general to keep the scums from the two carbonatations entirely separate, but in some beet sugar factories it is the custom to mix and filter them together, a more easily treated material being thus obtained. This is a process not recommended by the best authorities, the interaction of the two scums tending to reintroduce into the juice bodies which it is desired to eliminate.

In the carbonatation process the quantity of lime used is very considerable and it is essential that labour-saving devices be used in connection with it. A factory of moderate size working up 5,000 gallons of juice per hour will use about 500 gallons of milk of lime, equivalent to about 500 lbs. of dry lime. The milk of lime may be mixed on the basement and elevated to the clarifier loft by a pump or montjus, or the dry lime may be itself elevated by means of a hoist. In either case power is required to drive the lime mixing apparatus. This consists of a rectangular or cylindrical tank of suitable capacity, in which is placed centrally a vertical shaft, fitted with a series of horizontal blades. On the top of this shaft is fixed a horizontal bevel wheel gearing, with a vertical one which receives its motion by

belt gearing from any convenient shafting, the power required not being sufficient to demand a separate engine; the liming tanks have similar appliances to ensure a complete mixture of lime and juice.

The carbonating or saturation tanks, *Fig. 51*, are made either rectangular or circular; the latter form is preferable as tending to a more uniform distribution of the carbon dioxide. They are often

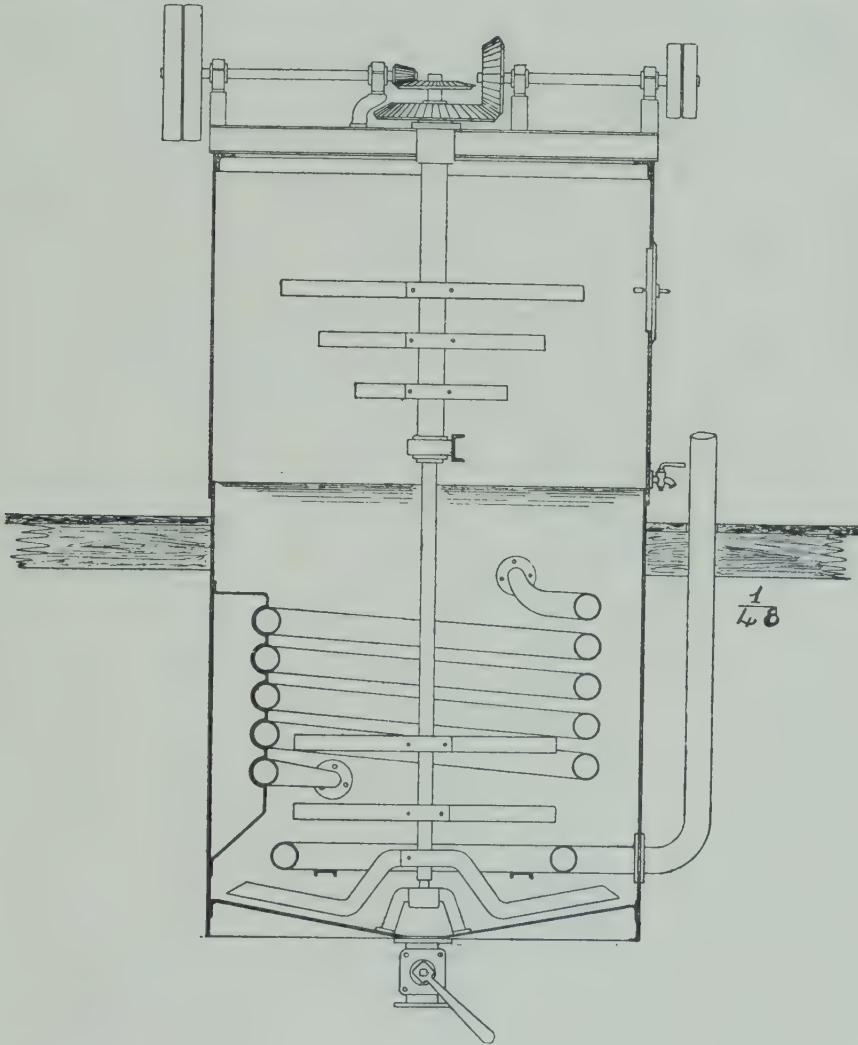


FIG. 51.

provided with an iron lid, to which is fitted a short chimney. Where this device is not utilised the froth is broken up by means of a jet of steam brought to play upon the surface. A mechanical arrangement, consisting of a scraper passing over the surface of the juice, is sometimes used, and a stirring device, as shown in *Fig. 51*, is also employed.

The height of the liquid undergoing treatment varies in practice from four to nine feet, and owing to the frothing the vessels are not

filled to within one or two feet of the top of the containing vessel. No useful purpose is served by decreasing the height of liquid, as if too low there is danger of carbon dioxide passing away unutilised.

To distribute the gas uniformly through the liquid various devices are used. The commonest method is to use a perforated coil, for which may be substituted a perforated disc or drum: any method which secures uniform distribution of gas is effective. In addition to the gas distributing coil, steam coils are provided for boiling the

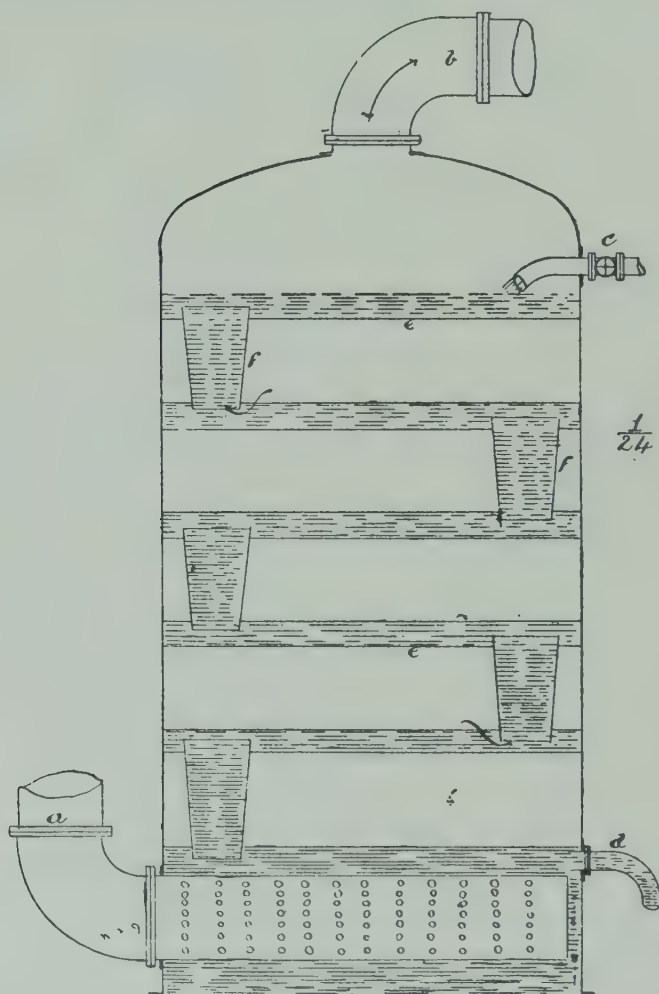


FIG. 52.

juice; an allowance of one square foot heating surface for every two gallons capacity is sufficient.

The carbon dioxide used in this process is, of course, generated on the spot by burning limestone; after being generated in the kiln, the gas is passed through a gas washer, a form of which is shown in *Fig. 52*; it consists of an upright cylindrical vessel in which is placed

a series of transverse horizontal partitions *e*; in each of these, and projecting a few inches, are fitted the funnels *f*; water is pumped into the vessel by the pipe *c* and flows over the partitions, down through the funnels and out through the pipe *d*. The gas from the kiln enters by the pipe *a*, the lower end of which is perforated, and flows upwards in the direction indicated by the arrows. In the passage of the gas the dust carried over is deposited and the gas cooled down to a temperature of 40°C. Various other forms of gas washers are made; in one, perforated plates take the place of the transverse partitions described above. Any of the forms of jet condensers described in connection with evaporation serve equally well as gas washers.

In certain beet factories the gas evolved from the kiln is purified by being passed through closely-packed carbonate of soda or through a solution of this substance; the object of this procedure is to eliminate any sulphurous acid which may be present, as the coke employed contains sulphur.

The carbon dioxide requisite for the carbonatation process is obtained by burning lime in kilns at the factory, which in this case makes its own temper lime from crude limestone. Lime kilns are of two types, *continuous* and *intermittent*, and the former of course is the type required for a sugar factory. They may also be classed as *long flame* and *short flame* kilns. In the former the fuel is burnt on a hearth, and the products of combustion pass through the limestone in the kiln proper. In the latter the fuel and limestone are mixed together and charged into the kiln from the top. It is very general to use a combination of short and long flame burning. The latter is more expensive as regards fuel, but gives a purer product, as in short flame burning the lime is contaminated with the ash of the fuel. When using good quality coke, with short flame burning, two per cent. of the product consists of the ash of the fuel. When wood is used a rather larger percentage is present.

In *Fig. 53* is shown a section of a continuous type of kiln very generally used in beet factories, which can be employed as a long or short flame kiln, or as a combination of both methods. The kiln consists of a tapering masonry shaft of forty to fifty feet high; the diameter at the base is fifteen feet, and at the beginning of the curved portion twelve feet. Many kilns are built with much narrower shafts—a diameter of eight feet for a height of fifty feet not being uncommon. The interior of the kiln is lined with fire-brick, *d*; the

exterior being of common brick, *e*; the whole is sometimes cased with iron plates to prevent leakage of air through the masonry, and sometimes a layer of non-conducting material is placed between the fire-brick and outer casing. The base of the kiln is conical so as to allow the lime to gravitate towards the doors, *b*, of which there are eight, provided for the removal of the burnt lime. The limestone, or mixture of limestone and fuel, is introduced into the kiln at the top, which is kept closed by the cone, *k*. A charge being dumped on to the cone from the waggon, *h*, the cone is lowered by moving the

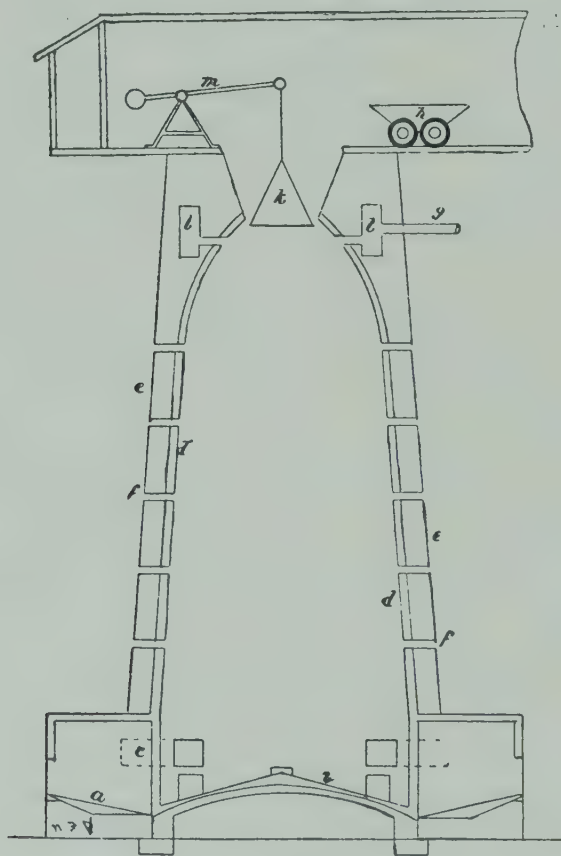


FIG. 53.

lever, *m*, and distributes the charge evenly in the kiln. At *f* tubes are let into the wall to allow of the process being watched. These tubes are provided with shutters so as to regulate the supply of air. At *a* are the hearths on which the fuel is burned, the products of combustion passing by way of *c* up through the kiln; three or four hearths are usually provided. The products of combustion pass by tubes to the chamber *l*, whence they are aspirated by a pump to the gas washer, and eventually to the carbonating tanks. The lime (and

fuel where the two are mixed) are raised to the platform at the top of the kiln by a pulley hoist, and in very large installations by a hydraulic lift.

The pumps used to aspirate the carbon dioxide are now slide valve pumps similar in design and construction to those used in the dry vacuum process described in the chapter on evaporation. A table of their capacities is given below.

Quantity of gas sucked per hour c.b.m.	50	825	1050	1300	1800	2050	3375	4050
Diameter of steam cylinder m.m.	275	350	375	400	470	500	600	700
Diameter of carbonic acid cylinder m.m.	500	550	600	650	750	800	1000	1100
Piston stroke m.m.	470	550	550	630	700	700	800	1000
Revolutions per minute..	75	70	70	65	60	60	55	45
Steam inlet m.m.	60	80	80	90	110	110	140	170
Steam outlet m.m.	70	90	90	100	120	120	150	185
Diameter of suction pipe m.m.	110	125	135	150	175	190	240	270
Diameter of delivery pipe m.m.	100	110	125	140	160	170	220	250

A very complete study of the lime kiln has been made by Gallois, from whose researches the following notes are taken. The investigation, of course, refers to beet sugar manufacture, but as the amount of lime used is the same per ton of cane or beet, his results are applicable to the cane sugar industry. Gallois' figures are expressed in the metric system, and these have been converted by the writer to English units.

A lime kiln for short flame burning without hearths should have a capacity of 14 cubic feet per ton of cane per 24 hours. For the decomposition of 100 lbs. limestone of 95% purity, a theoretical minimum of 6 lbs. coke is required; this corresponds to one volume coke to six volumes of limestone. In practice, from four to five volumes of limestone are used with one volume of coke, and some authorities allow three volumes.

Coke gives twice the calorific value of average wood, and accordingly 12 lbs. wood to 100 lbs. limestone would be required.

The following are the points to be observed to obtain a good result in the kiln :—

1. The limestone should contain a minimum of silica and alumina.
2. Washed coke, containing not more than 7% of ash, should be used.
3. The proportion of coke and limestone should be carefully regulated.
4. The charges should be frequent and regular.
5. The lime should be drawn successively from the doors in turn.
6. Only two-thirds of the volume of the kiln should be occupied.
7. The aspirating pump should work slowly and regularly.
8. Air should not be allowed to suck back through the gas pipe.

The objectionable constituents which occur in limestone are silica, alumina, magnesia, and sulphate of lime. If either of the two former are present during the calcination, fusible silicates and aluminates of lime and magnesia are formed, giving rise to what is known as *scaffolding* in the kiln—*i.e.*, a fused mass is formed, preventing the descent of the lime. In addition, their presence prevents the lime slaking properly; furthermore, silica introduced into the juice may dissolve in the presence of alkalies and be precipitated as scale in the evaporators, besides causing difficulties in the filtration. Magnesia and sulphate of lime also cause scale in the evaporators.

Below we give analyses by MM. Gallois and Dupont of different types of limestone :—

Material.	Bad.	Passable.	Excellent.
Moisture	4·10	6·25	1·21
Sand, clay, and insoluble matter..	4·50	3·17	0·55
Organic matter	1·20	1·12	0·41
Soluble silica	2·10	0·64	0·20
Oxides of iron and alumina	0·37	0·15	0·23
Calcium carbonate (limestone) ..	85·86	87·93	96·58
Magnesium carbonate.. .. .	0·95	0·53	0·50
Soda and potash	0·05	—	..
Undetermined	0·87	0·24	0·32

The inefficient working of a kiln may arise from the following points :—

1. Scaffolding, which may as already mentioned be caused by the presence of silica or alumina, and also by careless work in changing or in mixing the limestone and fuel.

2. Withdrawal of unburnt lime when too little fuel is used or when combustion is too rapid.

3. Presence of carbon monoxide, due to too little air being admitted for complete combustion, or to a too low temperature in the kiln.

4. Presence of air due to leaks in the masonry or to air sucking back, or to working the pump too fast.

The composition of the gas from the kilns varies within wide limits, the theoretical maximum of carbon dioxide being 38·7%; in general practice the percentage lies between 25% and 30%, with from 1% to 3% of oxygen and 65% to 70% of nitrogen. Traces of carbon monoxide may be present but should not rise above 1%; sulphur dioxide derived from sulphur in the coal may also occur.

The essential question with regard to any new process is whether a return is given on invested capital. An estimate of necessary working expenses for a factory working 1,000 tons of cane per day over a crop of 100 days is given below.

The necessary extra plant over and above that necessary for the ordinary defecation process will include a limekiln, gas washer, and carbonic acid gas pump; and the carbonating tanks simply replace the clarifiers and eliminators used in the defecation process.

The cost of these may be estimated as: limekiln £3,500; gas washer, £150; carbonic acid pump, £600; a total cost of £4,300.

The extra current expenses for a crop of 100,000 tons will include purchase of limestone sufficient to give 1,500 tons of lime, for which would be required 2,678 tons pure limestone, or, say, 2,900 tons actual crude material. In certain instances, such as in Mauritius, estates near the sea board could lay the coral reefs under contribution, and obtain limestone at the factory at a cost of 2s. to 3s. per ton. Then the lowest cost of the limestone would be £435, but in other cases, such as in Demerara, the cost of transporting limestone would be prohibitive.

In general, in beet sugar factories eight pounds of coke are required per hundred pounds of limestone; wood, in general in tropical countries, is cheaper than coke, and taking the relative calorific value of wood to coke as 1 : 3, twenty-four pounds of wood will be required per hundred pounds of limestone, and for the 2,900 tons of limestone 696 tons of wood; in very favourably situated estates wood can be obtained at the factory at a cost of 6s. per ton, giving the cost of fuel as £208 16s.

The extra labour in working the kiln may be put at five men per shift, and for the hundred days' campaign will cost £60.

The large quantity of water added with the milk of lime requires additional expense in evaporation, if the 1,500 tons lime be added at a density of 20° Balling; approximately 6,000 tons of water are also added. Allowing at triple effect one pound of coal to evaporate twenty pounds water, 300 tons of coal will be required, which, at 25s. per ton (a price frequently reached in the tropics), will cost £375.

The total extra cost then, allowing 10% interest and depreciation on invested capital, will be for the 100,000 tons of cane £1508 16s., or 3·621 pence per ton of cane, and allowing a 10% recovery on the canes, 3s. per ton of sugar; and this is an estimate made for circumstances more favourable than would generally be the case.

To counterbalance this extra cost the value of the crop must be increased, and an increase can only be looked for on the score of quality, as the figures published by the West Java Experiment Station show conclusively that no greater extraction is obtained by this process.

In making high-class white sugars for direct consumption, an expenditure of 1s. 6d. to 1s. 9d. for chemicals (including lime) per ton of sugar is usual. The difference between this amount and that estimated as the expense of the carbonatation is really very small compared with the profits on a ton of sugar expected to be realized on a large, well-managed estate. Very slight differences, such as a larger yield in first product in one case, would turn the scale very decidedly in favour of one or other of the processes.

What is, however, claimed as an advantage for the process is, in certain cases, one of its greatest drawbacks, and that is the destruction of the glucose. In countries such as Java and Mauritius, where either from excise reasons or want of a market rum or arrack cannot be made, loss of glucose is of no consequence, but in districts such as Demerara where the rum forms a very important bye-product, any destruction of glucose is a direct and serious loss, which would at once put the process on an uneconomical basis. Where, however, rum is not made and fuel and limestone can be cheaply obtained and a gummy impure juice is to be treated, the process might meet with financial success.

CHAPTER XIII.

THE FILTRATION OF THE JUICE.

The filtration of the juice has for its object the removal of the suspended impurities. Two applications of filtration in a sugar factory may be distinguished,—scum filtration and filtration *en masse*. Filtration through animal black is not considered, as its use is now obsolete in cane sugar factories.

In general in cane sugar factories scum filtration alone is used, and the method followed is usually as below:—The scums are separated from the juice by one or other of the methods described in a previous chapter, and received in tanks provided with a steam coil. A further quantity of lime is added, the scums brought to the boiling point, and forced through the filter-presses by means of a pump or montjus. The juice is further cleaned after filtration from the bulk of the scums by boiling and skimming. This method is open to the following objections:—The boiling of the juice, in order to bring the scums to the surface, requires a very considerable expenditure of heat, the evaporation in the process often increasing the density of the juice as much as 2° Balling; this point is more fully discussed when dealing with the fuel value of megass. The expenditure of heat is greatest when consumption sugars are being made, and the boiling may be entirely dispensed with when refining crystals form the output. A much more rational method is to filter the partially clear juice through the mechanical filters described below. Further objections to boiling the juice are that in the presence of an accidental excess of either lime or acid, decomposition of the sugar at the high temperatures is to be feared. The forms of filter in use are either the Taylor bag or stocking filter, or the frame filter-press invented early in the last century by Howard. The former consists of a long bag or stocking of stout cloth, generally about six feet long and four inches in diameter; these stockings are suspended in groups of from twenty to fifty in a horizontal frame; the frame is perforated with holes in rows a short distance apart; into the holes are fitted gun metal sockets furnished with screw threads for the reception of the gun metal cones to which the bags are tied. The whole system of frame

and bags is enclosed in an upright iron box, access to which is afforded by means of close-fitting doors; the sides of this box project a height of about two feet above the frame; the scums being allowed to flow over the frame, the clear juice passes through, the dirt being retained in the stockings. A steam connection is usually fitted up in the interior of the box so that the high temperature necessary to rapid filtration may be maintained. A view partly in section and partly in elevation is shown in *Fig. 54*.

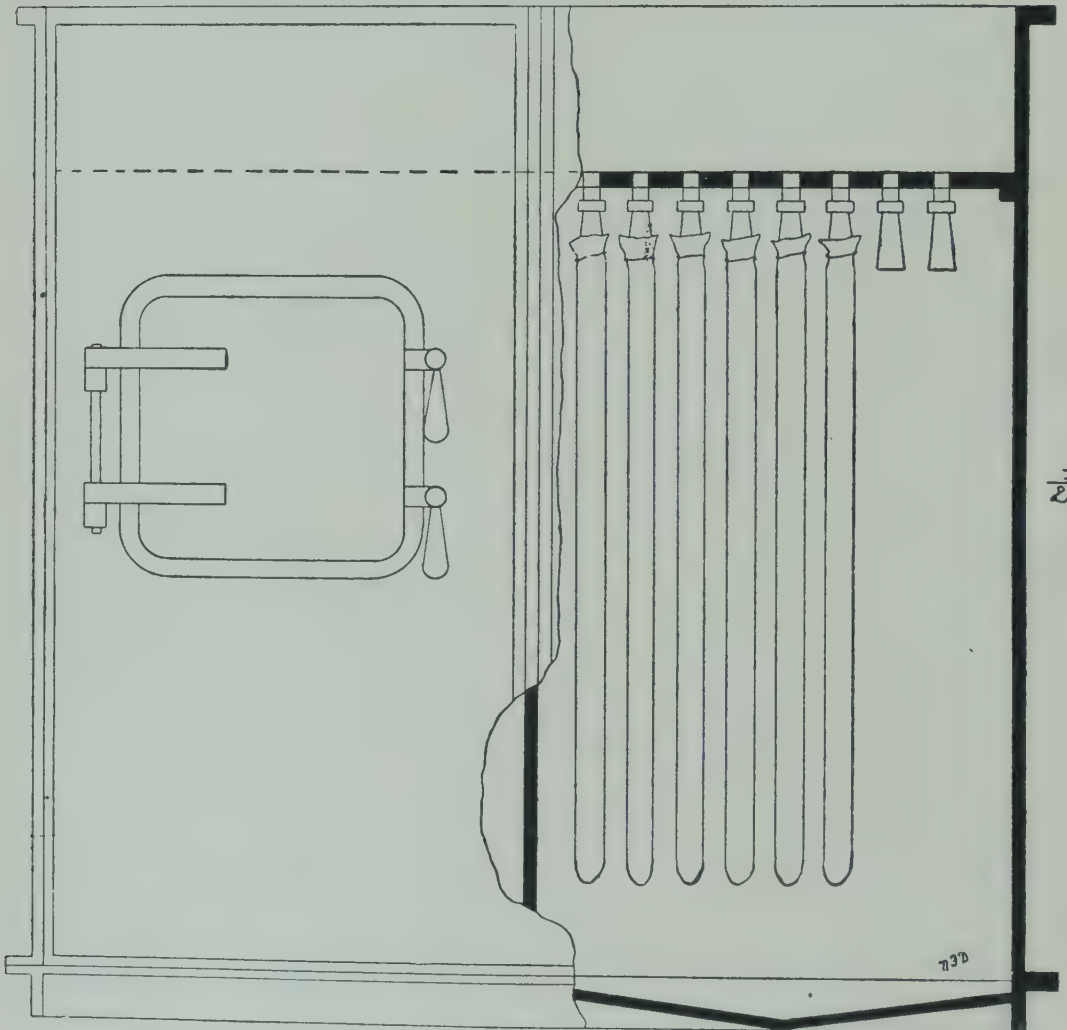


FIG. 54.

In *Fig. 55* is shown a view partly in section and partly in elevation of a central feed frame filter press; it consists of a heavy cast-iron frame *b*, on which are supported a number of plates *c*; on the sides of the plates are cast lugs from which the plates depend. The latter are made either square or circular, generally the former.

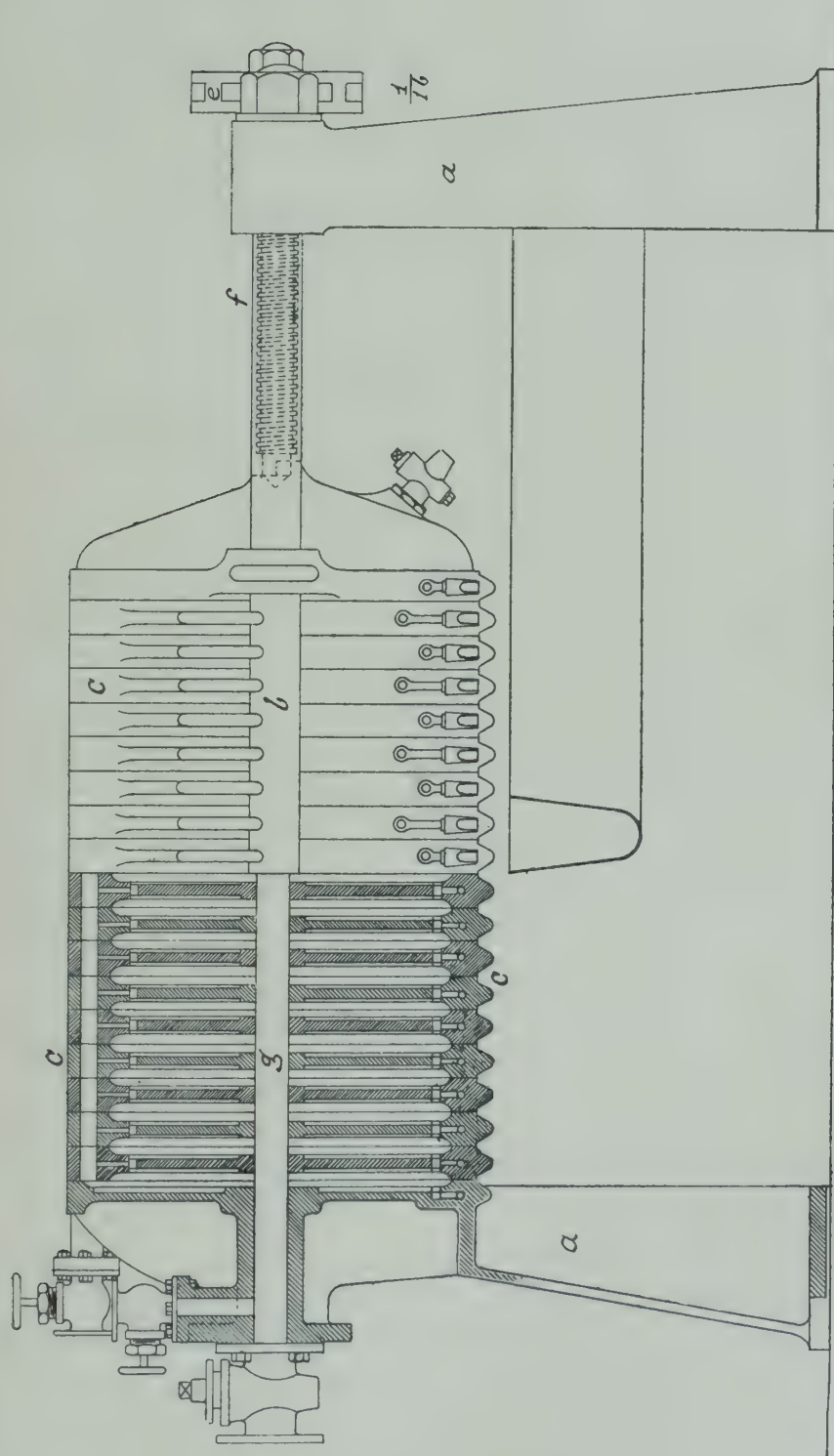


FIG. 55.

On their surface are formed a number of corrugations about one quarter of an inch deep; in the centre of each is an opening so that when all the plates are fixed in position there is a circular conduit running through the press. Near a lower angle of each plate is an aperture which communicates by a channel with a cock placed at the bottom of one of the sides of the plate, and through which the filtered juice is drawn off. Filtration is made through strong twill cloth, as a general rule, but in the absence of other material ordinary gunny bags form an efficient substitute. Cloths, with circular holes cut to correspond with the holes in the plates, are hung over each plate. The edge of the cloth is secured in the hole in the plate by means of a hollow screw with a deep rim. In working the press after all the cloths have been placed in position, the whole is screwed tight by means of levers acting on the wheel *e*, which works the screw thread *f*, and by means of suitable piping juice is pumped or forced by a montjus through the press along the conduit *g*; the clean juice passes through the cloth and the suspended dirt is caught between the cloths. At the upper corners of the plates are openings communicating with another set of piping by means of which water or steam may be forced through the scum after the press is filled. This type of press is not very convenient, the bags have a great tendency to tear away at the centre, and washing to remove sugar in the cake is not, as a rule, effective. A rather different system is now usually followed. In *Fig. 56* are shown, in section, the types of plate used. One plate is solid, and the other consists of a frame only, *a*. The solid and hollow plates are placed in the press alternately. At the angles of both frame and press are the circular openings *b* and *c*, so that in this press there are two conduits, that at *b* is for the passage of the juice, and that at *c* for the washing water. The channel *h*, in the hollow plates, conducts juice to the interior of the press, and in the solid plates there is a similar channel, *i*. A light joint is made along the conduits by placing indiarubber rings, *d*, in the closed openings *b* or *c*, as the case may be. At *g* in the solid plate is an opening communicating with the cock *f*. Bags without openings are hung over the solid plates, but do not cover the conduits *b* or *c*. Scums being forced into the press by the conduit *b*, pass through the channels *h* and fill the spaces between the two solid plates formed by the hollow plates. The clear juice passes out through *g*, the scums being caught between the bags. To wash the cake, water is forced through the conduit *c*, and passes through the cake in a direction opposite to that

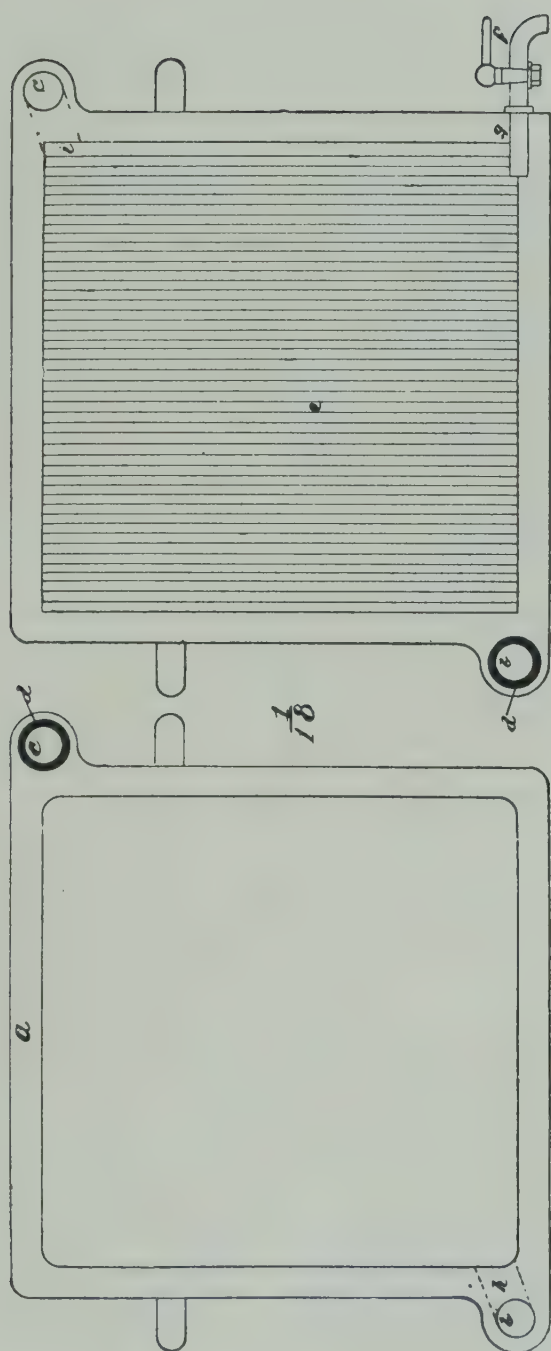


FIG. 56.

by which the juice travelled. The advantage of this type of press over the central feed press is that the washing is more effectually performed, and that the bags not needing to be cut have a longer life.

The allowance of filtering area required for scums is on an average two square feet for every gallon of scums per hour, and an allowance 25 % in excess of this is necessary to allow of the presses being emptied and cleaned.

The limit to which washing should be carried depends on the sugar content of the juice, and also on the liability of the dark coloured washings to spoil high grade sugars. The very dilute last washings are in beet sugar factories used to make up the milk of lime there employed in much larger quantities than in cane sugar factories. A use for the last washing can be economically found in the maceration process* or to break down the molasses for reboiling.

The loss of sugar in filter press cake depends on the purity of the juice as controlling the amount of cake formed and the degree to which washing is carried. With Taylor filters a cake, containing as much as 65 % to 70 % of water, and which cannot be easily washed, is formed. A loss of 2 % of the sugar in the juice can easily occur here. With well-pressed cake carrying from 50 % to 55 % water the weight of the cake averages rather under 1.5 % on the weight of the juice, indicating a loss without washing of .8 %—.9 % of the sugar in the juice. With moderate washing this loss, which is by no means negligible, can be considerably reduced.

When scums are of a peculiar consistency and persistently refuse to filter easily, the general remedy is to increase the lime put into the juice. Instead of doing this, the practice of forming a granular precipitate in the scums is sometimes followed, any body which forms a granular precipitate with lime such as sodium carbonate may be used; another body which lends itself readily to this process is oxalic acid, in this case about one per cent. of a concentrated solution of oxalic acid is mixed with the scums, more lime being added afterwards to neutralise the excess of the acid.

Filtration of the juice after separation from the scums is practically universal in beet sugar factories and should always be made in cane sugar factories where high-class sugars are being made; the filtration

* These washings being very alkaline have a tendency, however, to dissolve the objectionable gummy bodies present in megass.

is made in what are termed *mechanical filters*, a large number of different designs, differing only in detail, being made.

In *Fig. 57* are shown sections at right angles to each other of a common type. The filter consists of an iron box provided with a false lid in which are fixed frames *a*. These frames consist of a lattice work skeleton over which is stretched a woven fabric, each frame is complete in itself and is called an element. A separate outlet is provided for each element so that any faulty one can be shut off. All the elements discharge into one common gutter. The juice enters the box at *d*, fills the box below the level of the false lid and passing from the outside to the inside of the elements discharges at *b*. In the form shown the elements are rectangular, while in some other designs they consist of cylinders, but the principle is the same in all.

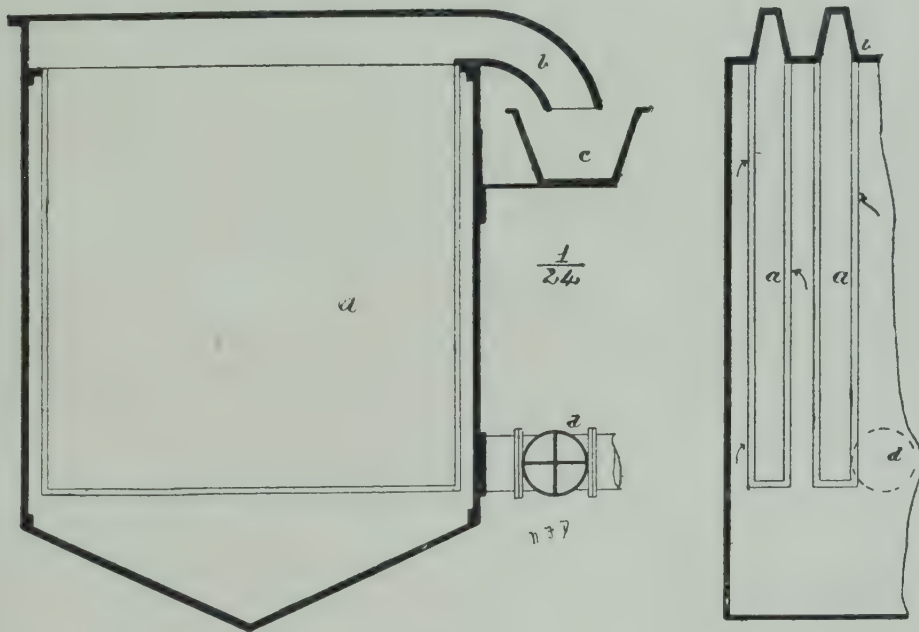


FIG. 57.

These filters are generally made with elements of one square metre filtering area, counting, of course, both sides, and in a chamber there will usually be about twenty to thirty elements. These filters will pass on an average ten gallons of juice per square foot per hour, but as much time is lost in changing cloths, they should not be calculated to pass more than seven gallons per foot per hour. They are also sometimes used to filter syrup on its way to the pans from the triple. When used for this purpose their capacity is only one-third or one-fourth of what it is for juice. They are usually worked under a head of six or seven feet.

In the last few years filtration of juices through sand has been largely adopted in place of filtration in the mechanical filters, and this method is universally stated to give brilliant transparent juices with a minimum of expense. The patented "Standard" sand filter consists of an upright cylinder about six feet high and twenty-eight inches in diameter, provided with a conical bottom. Arranged within the cylinder is a vertical perforated pipe about eight inches in diameter, which is also provided with a conical bottom. Between the pipe and inner wall of the containing cylinder are arranged a number of conical rings about three inches high, one ring standing on the top of the one immediately underneath. Sand is placed between the perforated pipe and the cylinder shell, forming a filtering surface between the rings; the juice enters at the bottom, fills the cylinder, passes through the sand into the perforated pipe, whence it is conducted away to a gutter. According as juice with coarse, or fine suspended, matter is to be filtered, the grain of the sand is varied; the size of the perforations in the inner pipe is also varied so as to prevent sand passing through. After use the sand is discharged and washed by a counter-current of water, but in the latest pattern the washing is conducted within the filter without discharge of the sand. The coral sand as found in Mauritius and other places forms an excellent filtering medium. Amongst other substances which have been proposed for use as filtering agents are gravel, kieselguhr, lignite, and slag wool.

The sand filters are also used to filter the partially concentrated juice as it passes from vessel to vessel, the object, of course, being to prevent deposit of scale on the heating surfaces of the evaporator.

The mending and washing of filter bags gives opportunity for labour-saving devices. Instead of employing a number of women to mend torn bags the whole work of a large factory can be done by a single sewing machine which may be driven off any convenient shafting. To wash the bags apparatus such as that employed in laundries, consisting of a cylinder in which is a revolving shaft carrying paddles, may be used. Not only is labour saved by this device, but the bags are less liable to be damaged.

The composition of filter press cake from the different processes of clarification is set out in the following analyses due to Geerligs:—

	Defecation Process.	Single Carbonatation.	Double Carbonatation First Saturation.	Double Carbonatation Second Saturation.
Water	69·72	—	—	—
Sugar	10·20	3·90	10·10	8·10
Glucose	·71	—	·38	—
Wax	4·12	3·43	2·48	—
Albumen	1·80	2·55	2·72	—
Fibre	—	3·08	6·10	·50
Organic acids....	—	1·94	2·12	4·20
Gums	—	1·11	1·20	—
Phosphate of lime	2·92	—	—	—
Silica	·37	8·48	1·85	·64
Iron and alumina	1·40	2·41	4·66	·51
Magnesia	·22	—	—	—
Sand and clay...	2·82	2·48	4·37	—
Calcium carbonate	—	67·94	61·94	85·01
Magnesium ..	—	1·80	1·21	—
Phosphoric acid..	—	·71	·87	·12
Undetermined ..	5·35	·17	—	·82

CHAPTER XIV.

THE EVAPORATION OF THE JUICE TO SYRUP.

By evaporation is meant the passage of a body from the liquid to the gaseous state. The term evaporation is usually restricted to that change which takes place continuously at the surface of a liquid, and ebullition or boiling to that which takes place throughout the entire mass.

Evaporation takes place continuously at the surface of all exposed liquids. The molecules or particles of matter, of which all bodies are supposed to be composed, have in a liquid but little attraction for each other, and tend constantly to fly off into space. In an enclosed liquid a quantity of vapour will be formed above the surface. The molecules of the liquid, in the form of vapour, are in constant movement, and will in their paths to and fro impinge on the surface of the liquid, which is at the same time constantly giving off vapour; eventually a point is reached when as many molecules leave the liquid as enter, so that a system in equilibrium obtains. When this state is reached the space above the liquid is said to be saturated, and no more evaporation (apparently) takes place.

The vapour given off by a liquid exerts a certain pressure which increases with the temperature; this pressure is known as the vapour tension. When the vapour tension of the liquid is equal to the pressure of the surrounding atmosphere, bubbles of vapour form in all parts of the liquid, and the liquid is said to boil; the boiling point of a liquid is then not a fixed figure, but is dependent on the pressure under which it occurs. The normal pressure of the atmosphere at sea level is equal to that exercised by a column of mercury 29.92 inches or .760 metre high; this is equal to a pressure of 14.707 lbs. per square inch or to 1.034 kilogram per square cm. At this pressure water boils at a temperature of 212°F. or 100°C.; if the pressure be decreased the boiling-point of water or any liquid falls, and it is due to this phenomenon that multiple effect evaporating apparatuses can be constructed, in which one pound of steam may evaporate in practice up to five or six pounds of water. A table is added at the end of this chapter, giving data connecting the pressure

and temperature of steam. The temperature at which a liquid boils is also influenced by the presence of bodies in solution; a table of the boiling-points of sugar solutions under atmospheric pressure will be found elsewhere.

When water or any liquid passes into the form of vapour, a certain quantity of heat is required to perform this change; this quantity is called the *latent heat of evaporation*. The heat required to raise the temperature of one pound of water one degree Fahrenheit is called the *British Thermal Unit*, and to convert one pound of water at 212°F. into steam at 212°F. requires 966 B.T.U. This quantity is the latent heat of evaporation of water; in centigrade units it is 537.6. A quantity often used in calculation is the *total heat of steam*; this means the quantity of heat required to convert a pound of water from the freezing point (32°F. or 0°C.) to steam at the given temperature. Thus to raise the temperature of a pound of water from 32°F. to 212°F. requires 180 B.T.U.; to convert it into steam requires 966 B.T.U., so that the total heat of steam at 212°F. is 1146 B.T.U.

Conversely to what has been written above, when steam is condensed to water it gives out the heat which was required to convert the water to steam. If then steam at 212°F. be condensed to water at 180°F. it gives up a quantity of heat which is the difference between the total heat of steam at 212°F. and of water at 180°F. This heat can be used to raise the temperature of or to evaporate water which is under such a pressure that its boiling point is lower than 180°F. ; the vapour or steam given off by the water thus caused to boil may be used to boil more water under a still lower pressure, and so on, and this process repeated to infinity. It is on these lines that the construction of multiple effect apparatuses is based.

The earliest method of evaporation was in pots over a naked fire, a system still pursued by the ryots of India and on a fairly large scale in Barbados, the whole system of tayches being called a copper wall. The earliest improvement over this method was the introduction of steam-heated pans, followed by the *Aspinall*, *Wetzel*, and other devices; all these consisted essentially of an open pan in which revolved steam-heated coils or discs, so arranged that half the coil was immersed; the rotating coil carried upwards a thin film of liquid and thus exposed a large surface to evaporation.

In 1865, Fryer introduced the *Concretor*, a patent which has been extensively used. In this plant the thin juice flows over a series of

trays placed over a flue, the whole being built on a slight incline; the flue is about forty feet long and the juice travels in a zigzag path about two hundred feet; reaching the end at a density of about 50° Balling, it flows into a revolving cylindrical vessel, in the interior of which are fitted scroll-shaped plates, so that, as the cylinder revolves, a large surface is exposed to evaporation; at the same time a current of hot air is blown through. After twenty minutes' treatment in this cylinder the evaporated juice sets on cooling to a solid mass, and is shipped to refineries for further treatment.

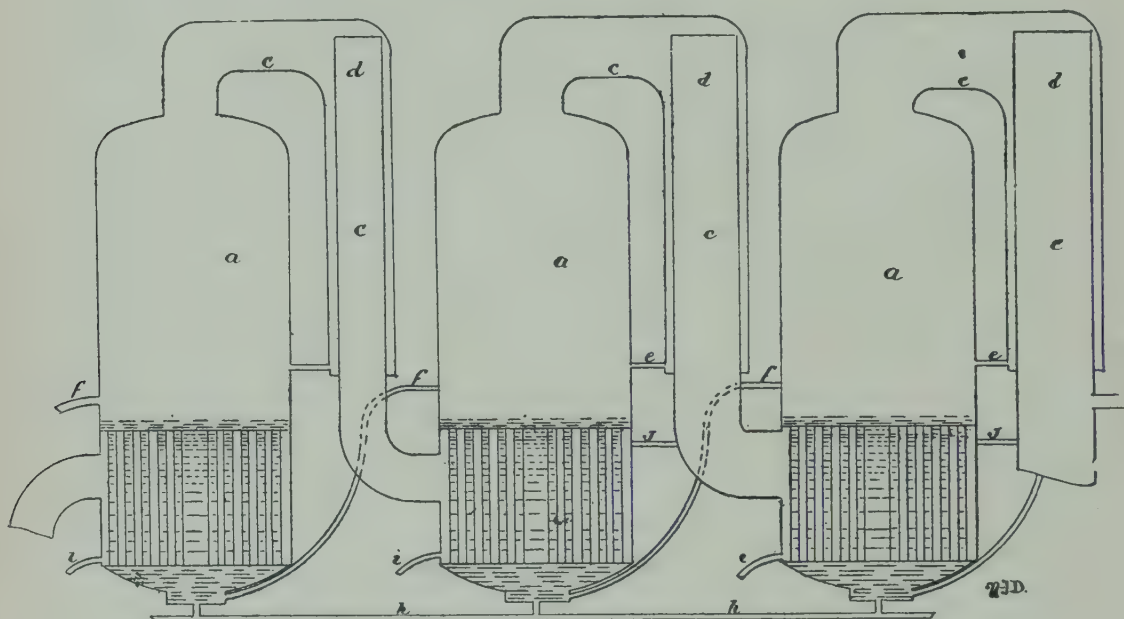


FIG. 58.

In modern factories evaporation is always performed in multiple evaporators. The principle on which these are constructed has already been indicated. The first multiple evaporator was invented in 1834 by Norbert Rillieux, of Louisiana, and was a double effect horizontal submerged tube apparatus. Apparatuses conforming to his original design and only differing in mechanical details are still largely constructed.

In *Fig. 58* is shown a diagrammatic sketch of a vertical submerged tube triple effect apparatus. Each body consists of an upright cylindrical vessel of height rather more than twice the diameter; near to the bottom and at about one third the height are placed two tube plates: these plates carry a number of tubes, the space between the tube plates and external to the tubes is filled with steam or vapour from a preceding effect; the vapours pass over from the juice in one

vessel to the calandria of the next by means of the vapour pipe *c*. In each vapour pipe is often placed a cylindrical baffle plate *d* for the purpose of intercepting any juice carried over in entrainment: any juice so intercepted is returned by the pipe *e* to the vessels. The juice circulates from vessel to vessel by the pipes *f* under the influence of a difference in pressure or aided by a circulating pump; the concentrated juice from the last body is pumped out against atmospheric pressure; very often this pump is worked off the main vacuum pump. The water of condensation in the calandrias of the vessels passes out through the pipe *i*; generally steam traps of various constructions are used or the water may be removed by a small pump. In some designs the water of condensation is passed from vessel to vessel, affording a slight economy of heat. The pipe *h* is for the purpose of introducing acid or alkali to cleanse the tubes of scale and *j* is a small pipe carrying the incondensable gases from the second to the third vessel and thence to the pump.

The method of operation is as follows: juice is allowed to flow into the vessels from the supply tank until a little above the level of the upper tube plate; the vacuum pump is then started, and a vacuum of about twenty-five inches, corresponding to a pressure of about five inches, obtained in the last body of the apparatus, and the water injection cock opened. Exhaust steam at a pressure of about five pounds per square inch is admitted to the calandria of the first body; the juice boils and vapour passes over into the calandria of the second body, into which juice from the first body has already passed; the tubes in the second body act as a surface condenser to this vapour. The condensation of this latter creates a partial vacuum in the first body, and by its condensation parts with its latent heat to the juice in the second body, causing this juice to boil; a similar process takes place between the second and third bodies, and so on.

In this way one pound of steam could evaporate an infinite quantity of water; for reasons explained later on, the practical working limit is generally granted to be reached with quadruple evaporation. The majority of apparatus are, however, triple effects; but quintuple plants have been constructed.

Apparatus for multiple evaporation may be divided into three classes:—

1. Vertical submerged tube apparatus, often referred to as the "*Standard*" type.

2. Horizontal submerged tube apparatus, conforming to the original *Rillieux* and including the *Welner-Jelinek* apparatus.
3. Film evaporators, including the *Lillie* and *Yaryan* patents.

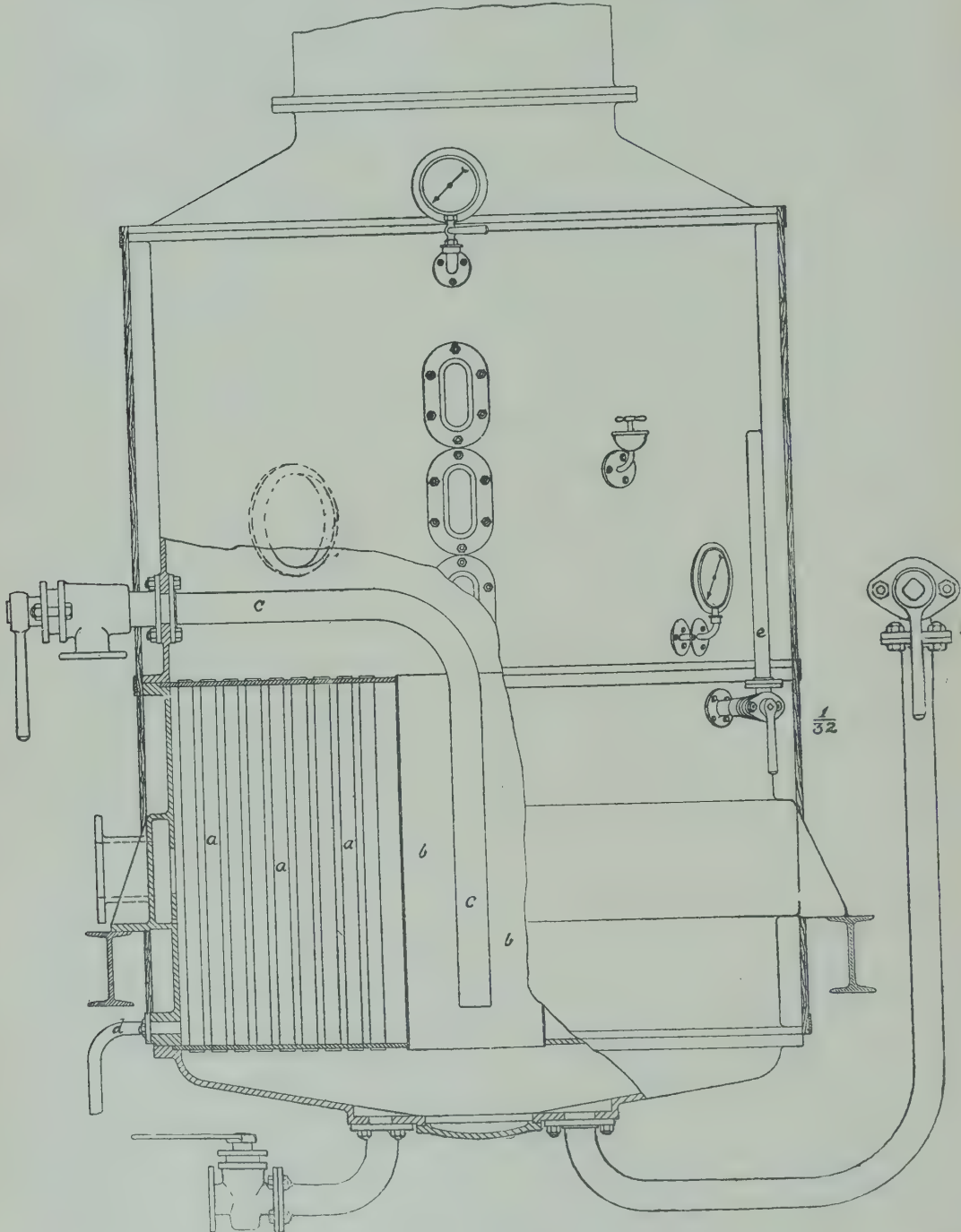


FIG. 59.

In *Fig. 59* is shown a vertical section of one body of a vertical tube apparatus. The evaporating tubes (*a*) are 3 feet long and 2 inches in diameter. They are constructed of copper or brass, and as regards

heat conductivity the former is preferable. In the centre of the tube plate is left an opening (*b*) about 2 feet in diameter. The object of this is to afford a good circulation for the juice. The juice inlet pipe (*c*) is shown dipping down this opening. By so arranging this pipe the juice is evenly distributed, and being lighter than the already partially evaporated juice, tends to rise and increase the circulation. In some designs this pipe ends flush with the wall of the apparatus to the detriment of the circulation. In the latest patterns the calandria is divided into two, three or four parts by means of vertical transverse partitions. Each division has its own steam or vapour intake (the

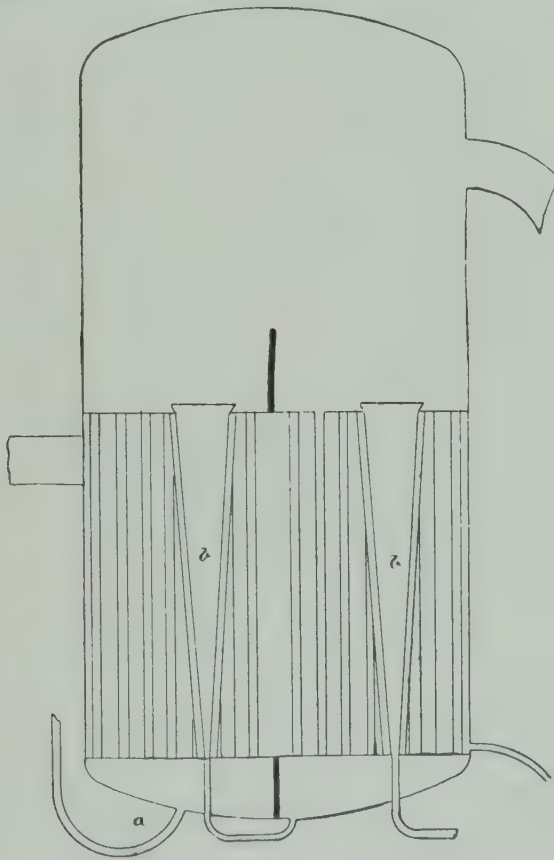


FIG. 60.

steam or vapour pipe being divided into a corresponding number of branches) and its own condensed water (*d*) and incondensable gas pipe (*e*). By this arrangement the even distribution of the vapour over the heating surface is assured and the removal of the condensed water and incondensable gases facilitated. With the calandria as one chamber there is a tendency for these two to bank up and so to diminish the value of the heating surface. The condensed water is sometimes passed from vessel to vessel, and from the last vessel to

the boiler feed tank. This arrangement while economising heat is objected to on the ground that sugar and other bodies may be carried over in entrainment and may damage the boilers.

Of special forms of evaporators, *Chapman's* design, *Fig. 60*, may be mentioned. The juice enters at *a* and flows upwards through the tubes and down through the funnel *b*. In the form sketched the vessel is divided into two parts by a vertical partition, affording a double circulation; in others the juice passes directly from vessel to vessel. Circulation between the different bodies is obtained by means of inverted syphons connecting the discharge of one with the intake of the next body, and these are of such a length that the leg connected

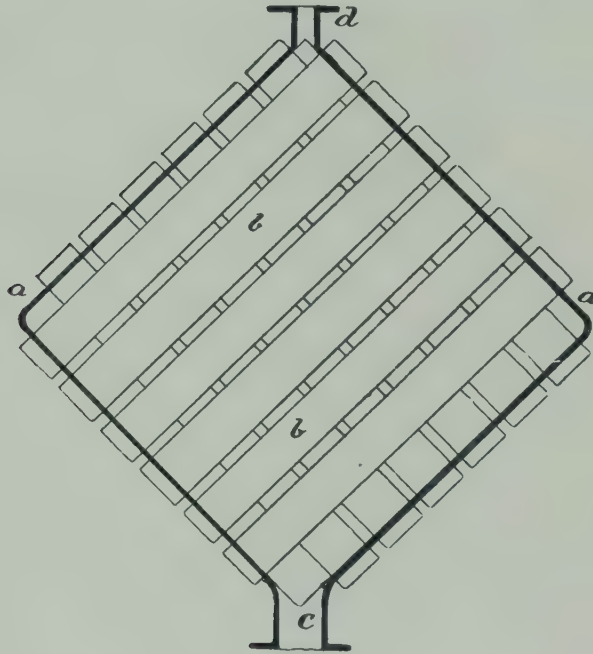


FIG. 61.

with the second body is from 12 to 18 inches longer than the column of liquid, which is due to the greatest pressure that can be possibly obtained between the two vessels. This apparatus is to a large extent self adjusting; there is only one cock to control the flow of juice into the apparatus, and the system of circulation prevents the juice in any vessel rising much above the level of the tube plate. In many standard pattern evaporators a space is left between the calandria and the shell of the vessel. Formerly, the shell of the vessel formed also the outer wall of the calandria; a better circulation was obtained by this means.

Some novel systems of arranging the heating surface have been recently developed on the Continent. In *Fig. 61* is shown, in section,

the radiating heater of Witcowitz. It consists of a forged steel body, *a a*, through which pass at right angles to each other a series of tubes *b b*. The juice circulates through these tubes, the heating steam being without the tubes and within the steel body; the condensed water and heavier gases are drawn off at *c*, the lighter ammoniacal gas at *d*. A very rapid circulation is claimed for this design; it is usually applied to the horizontal form of evaporator described below, and is also used as a heater in saturation and defecating tanks and is capable of application to the vertical form of evaporator.

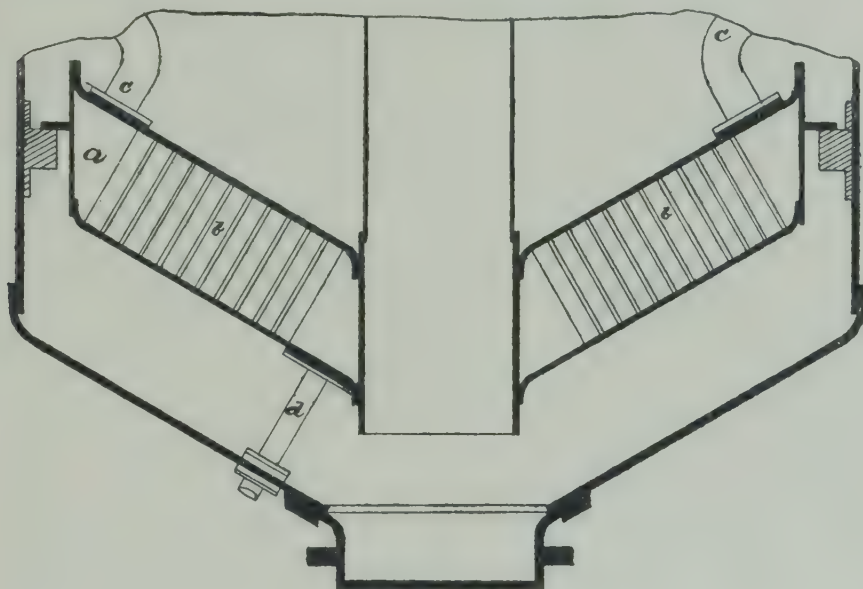


FIG. 62.

Another modification of the heating surface, known as the "Express" system*, is shown in section in *Fig. 62*. It consists of a belt *a a*, in which are arranged the tubes which form the heating surface; as in the Witcowitz heater above described, the juice circulates through the tubes *b*, steam entering the collector box at *c*, and the condensed water passing away at *d*. The collector box is set at an angle following the slope of the saucer of the effect, usually at an angle of about 30° from the horizontal; the tubes are about 18 inches long. In an effect entirely on this system there will be a second calandria above the one shown and placed in regard to it as a mirror image to the object. This design can be readily applied to effects with the ordinary vertical tube calandria, a belt being added to the effect below the existing calandria in which the additional heating surface is placed.

* English Patent, No. 1298 of 1903.

The horizontal submerged tube apparatus differ from the above in that the steam or vapour is contained within the tubes, the juice under treatment being outside; a longitudinal section of this form is shown in *Fig. 63*. The evaporating tubes are from five to six feet

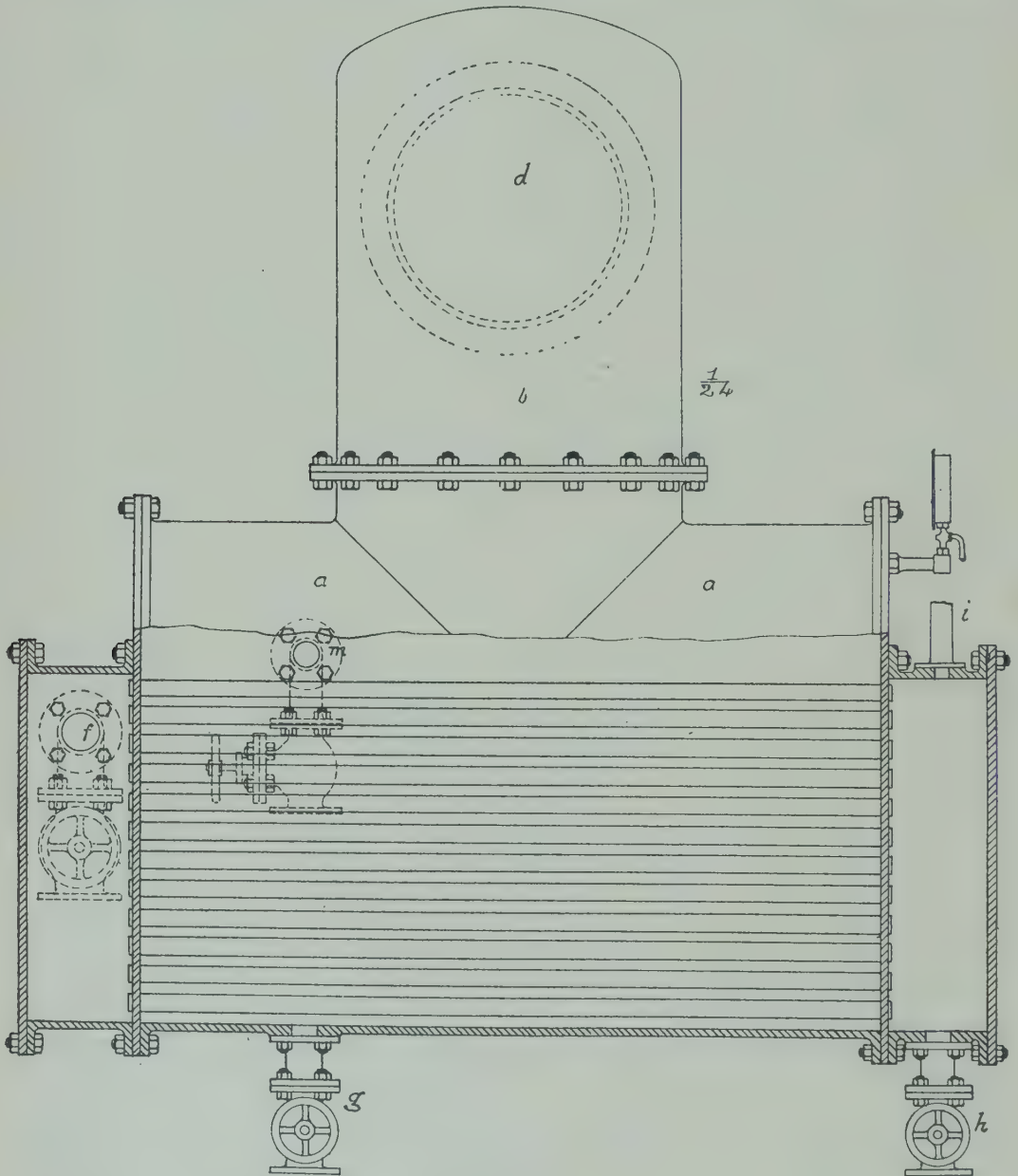


FIG. 63.

long, and are supported by vertical tube plates placed about twelve inches from the end; steam enters at the side at *f*, passes through the tubes, and after condensation is trapped at *h*; to facilitate the passage of the water the tubes are often set at a slight incline. It will be seen that the level of the juice in the vessels is, relatively,

much higher than in the vertical type. To prevent entrainment losses a very capacious steam chamber is placed over each vessel; the vapour main leads from this steam chamber to the calandria of the following effect. Plants of this type are not usually made by English firms, who prefer the vertical form; they are made to a certain extent in America, and are very largely used in Austria and Russia.

The *Welner-Jelinek* evaporator is a horizontal submerged tube apparatus differing very materially from the above, and is designed initially to have the height of the column of liquid under treatment as small as possible; the evaporating tubes are shown in end elevation and longitudinal section in *Figs. 64* and *65*. They are about twelve feet long and three-quarters of an inch in diameter; they are supported by tube plates at either end and by two intermediate tube plates shown at *j*; the tubes are generally arranged in nests of nine. The length and small diameter of the tubes necessitates the use of the intermediate tube plates, but at the expense of the longitudinal circulation. On reference to the drawing, *Fig. 65*, it will be seen that the steam or vapour entering at the valves *f* circulates through three sets of tubes; the rush of steam carries the condensed water along with it, the latter being trapped at *h* in the boxes at the end of the run. In some designs the condensed water is also trapped in the return boxes. The level of the juice under treatment is shown at *k*, the vertical height being only from twenty-two to twenty-four inches. The juice enters at *m* and leaves by the pipe *g*; a minute air vent is placed in the condensed water box at *i*. Above the main vessel, and communicating with it by two pipes *c*, is placed a save-all *b*, from which passes the vapour pipe to the next effect. Compared with the horizontal apparatus of the Rillieux type, the relatively small height of the column of juice, the large vapour space, and the method of steam circulation are to be noted. This type has been extensively used on the Continent, and especially so in Austria.

The Yaryan evaporator, shown in longitudinal section in *Fig. 66*, and in end sectional elevation in *Fig. 67*, consists of a horizontal body or shell of steel plate or cast-iron—depending upon size and steam pressure—within which is grouped a series of tubes about 3 inches diameter; these tubes are expanded into tube plates as shown, and at each end “return heads” are bolted on, thus forming a connection

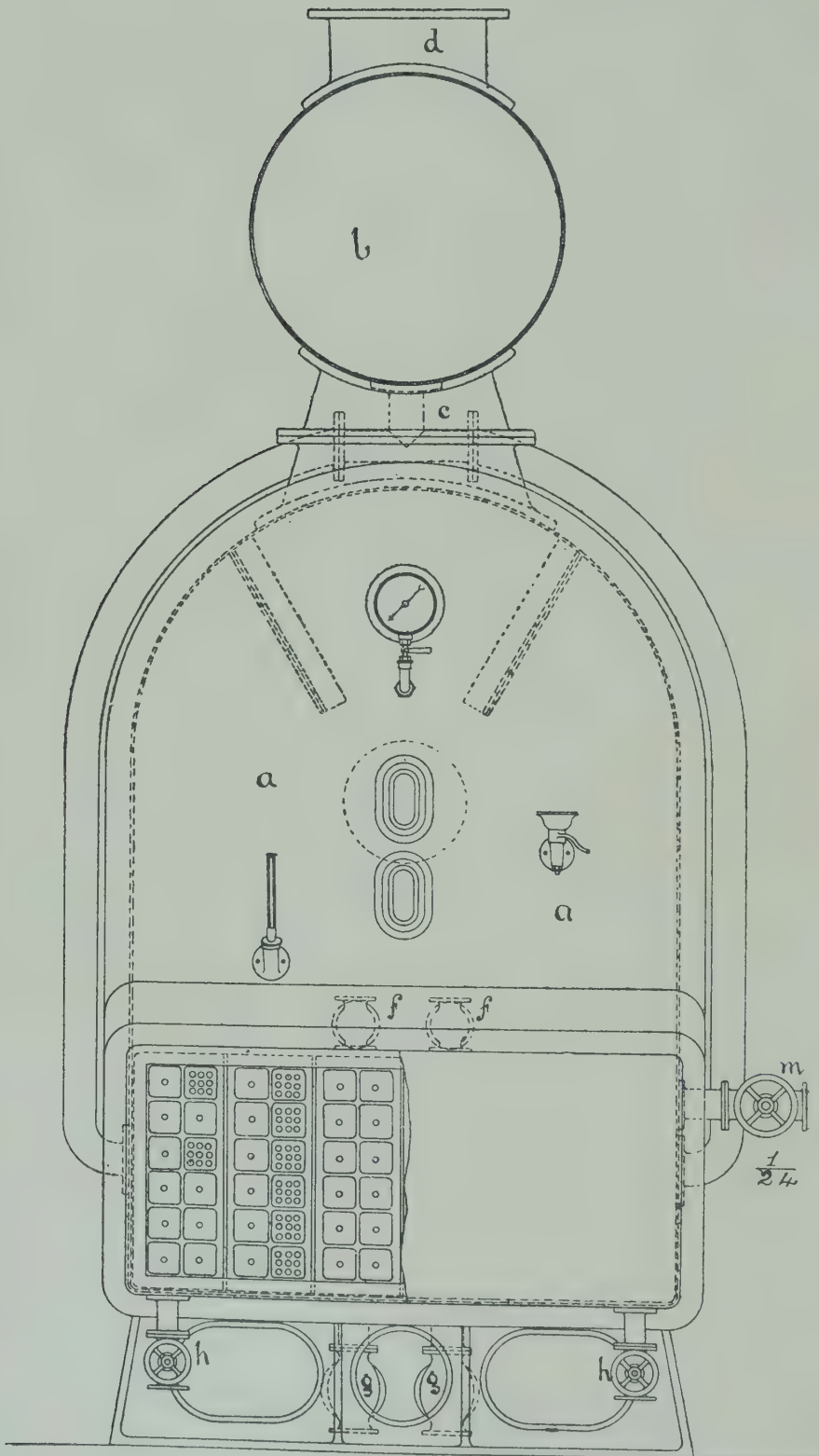


FIG. 64.

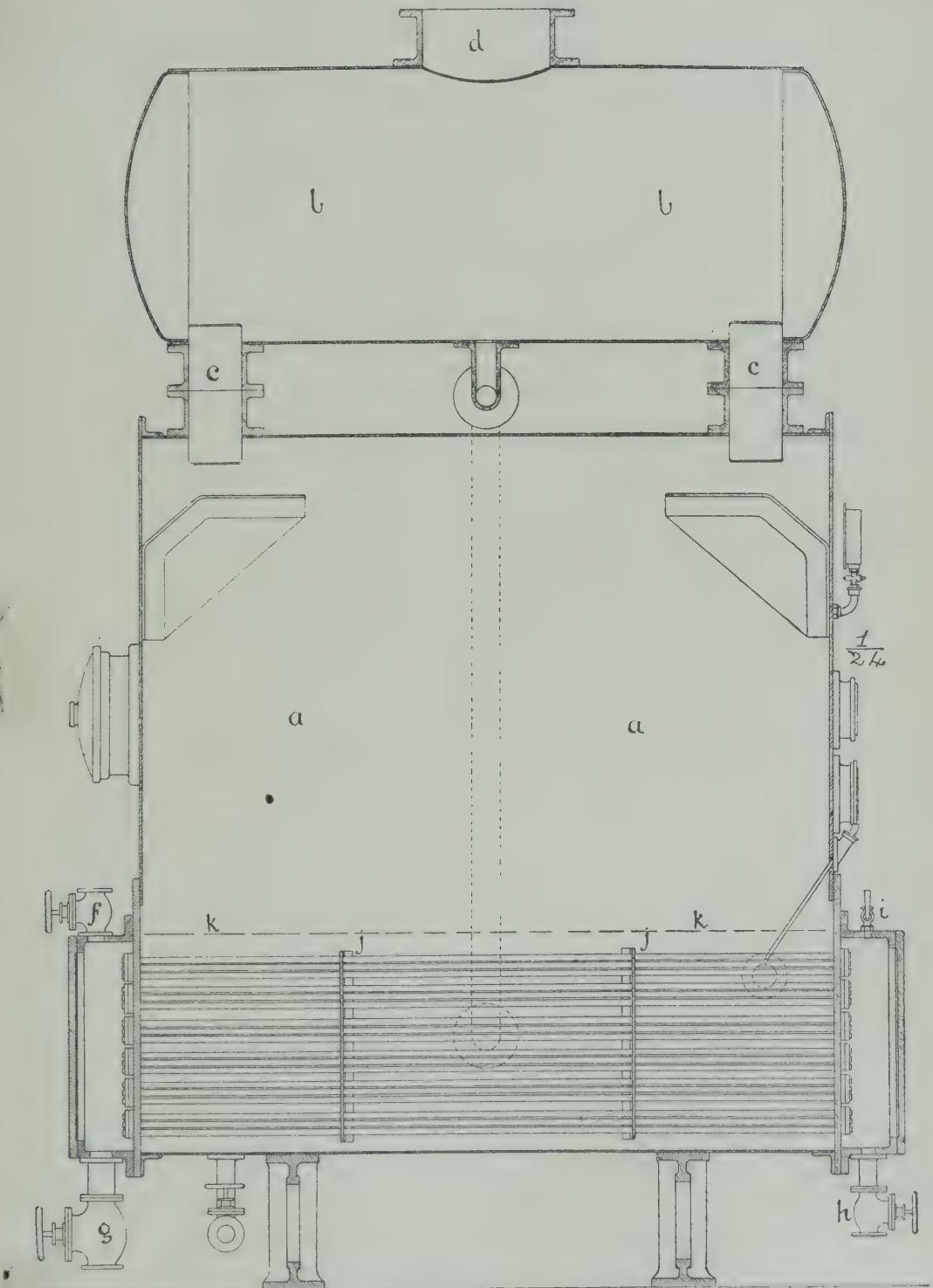


FIG. 65.

which ensures the continuous flow of the liquor through each coil or tube system.

Steam, or vapour from a preceding shell or effect, enters the shell at *e* and surrounds the outside of the tubes containing the liquor to be evaporated.

The liquor entering pipe *d* is forced, under pressure by a pump or otherwise, into the top tubes, and only partially fills their bore, thereby allowing space for the vapour arising from the heated liquor to pass freely away. The liquor passes along with a rapid and continuous motion through the series of tubes and discharges at *g*, the concentrated liquor and its vapour, passing along pipe *j*, falls into the separator *h*, shown in section in *Fig. 67*. The vapour passes, as indicated by the arrows, up and down the two baffle plates *b b*, where it emerges into pipe *k* which leads direct to shell of next vessel, or to condenser if from the last effect.

The concentrated liquor falls to the bottom of separator *h* and passes along pipe *i* to next shell for further concentration, and so on until, sufficiently concentrated, it has reached the last effect, when it has then to be pumped out owing to its being treated in a vacuum.

The *Lillie* horizontal tube film evaporator offers a system of evaporation radically distinct in mechanical details to any of the above. A vertical longitudinal section is given in *Fig. 68*, and in *Fig. 69* is shown an end elevation. The evaporating tubes are 5 to 6 ft. long and 3 in. in diameter; they are expanded into a tube plate at one end only to allow free expansion and are set at a slight incline to afford easy escape of condensed water; each tube has its own air vent at the end opposite to the tube plate. The juice is circulated by means of centrifugal pumps *c* all worked off one shaft; these pumps are of sufficient power to force the syrup out against atmospheric pressure. The supply of juice enters through the balanced valve operated by the float resting on the surface of the liquor in the float box *f*, and which permits the thin liquor to enter the effect and be added to the circulating liquor just fast enough to replace that passing away as vapour and through the discharge. The latter is controlled by the hand valve *g*; by opening it the discharge is increased, causing the level of the liquor in the float box to fall, and admitting a larger feed. The path of the juice is from the float box,

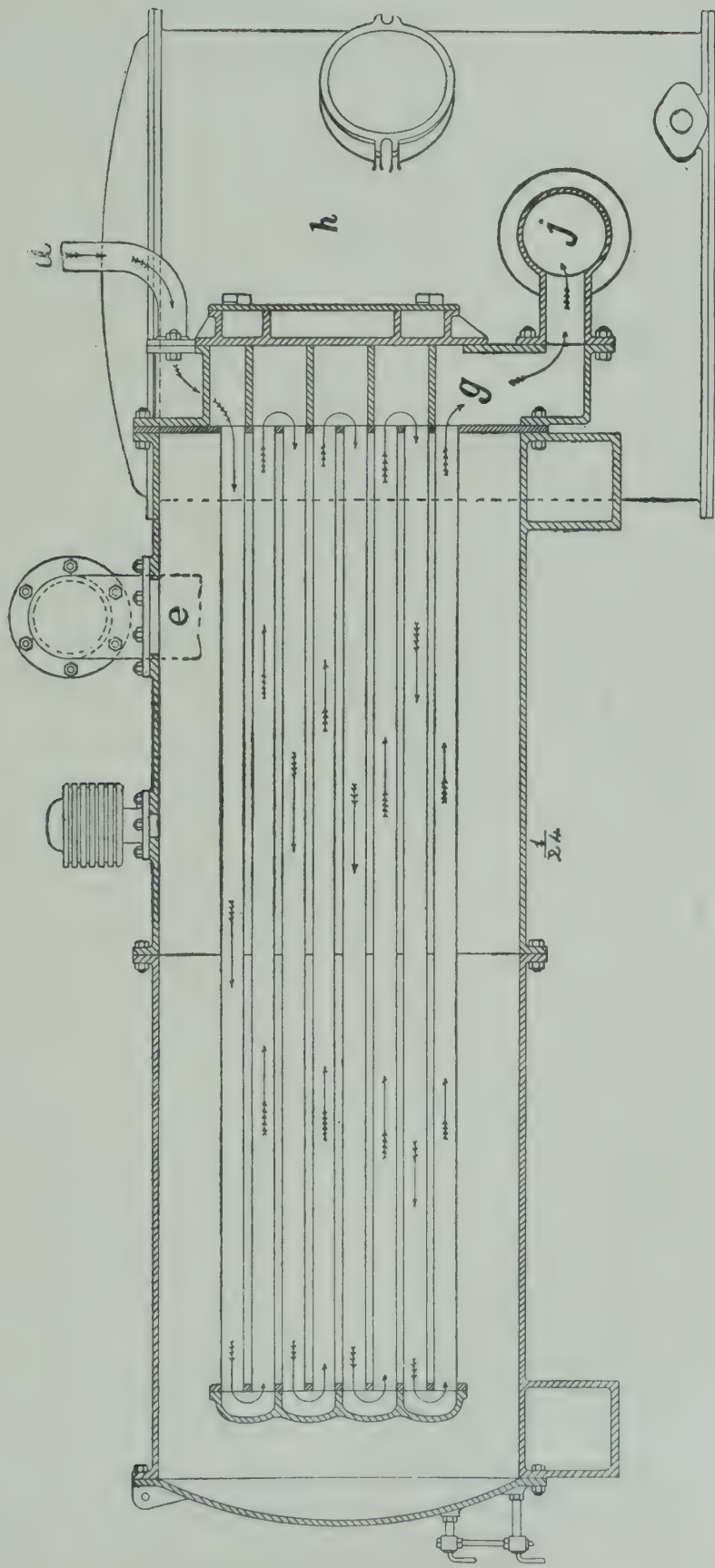


FIG. 66.

through the pump and connecting piping up into the manifold box on the back of the tube plate, thence into the several distributing tubes through the slots of which it passes as a fine shower over the evaporating tubes to the float box to again make the same journey, part

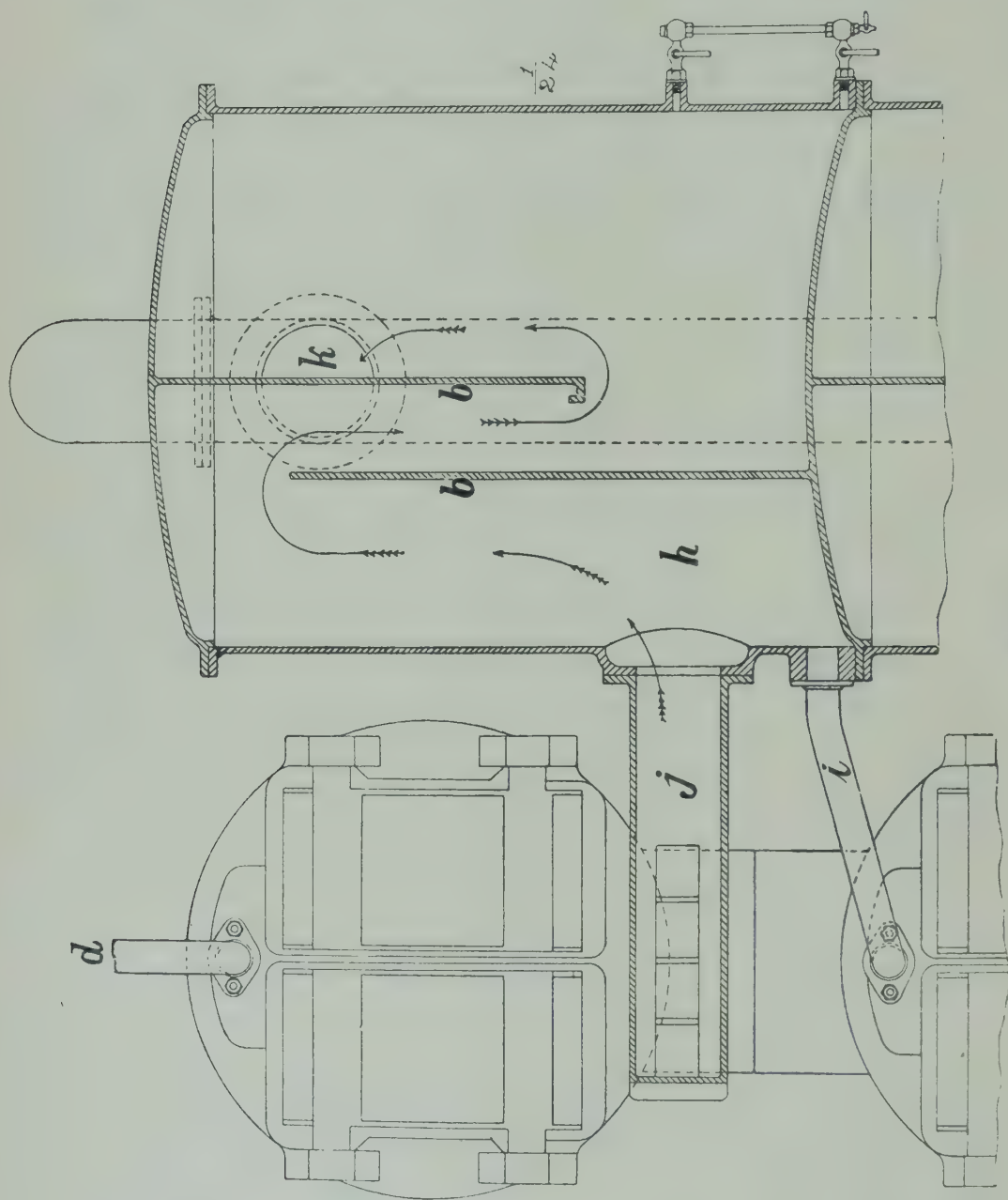


Fig. 67.

passing through the discharge pipe to the next effect. The steam enters by the pipe *g*, passes inside the tubes, the condensed water flowing down and being trapped at *i*, whence it passes on to the next effect, the evaporated vapour passes by way of *h* to the following body.

The *Lillie* evaporator differs from others in the following points. The juice under evaporation is always in a state of film or rain, and hence there is no tendency for the boiling point to be elevated through the pressure of a column of liquid and thus to diminish the efficiency of the heating surface. The quantity of juice in process of evaporation at one time is very small and is consequently under treatment but a

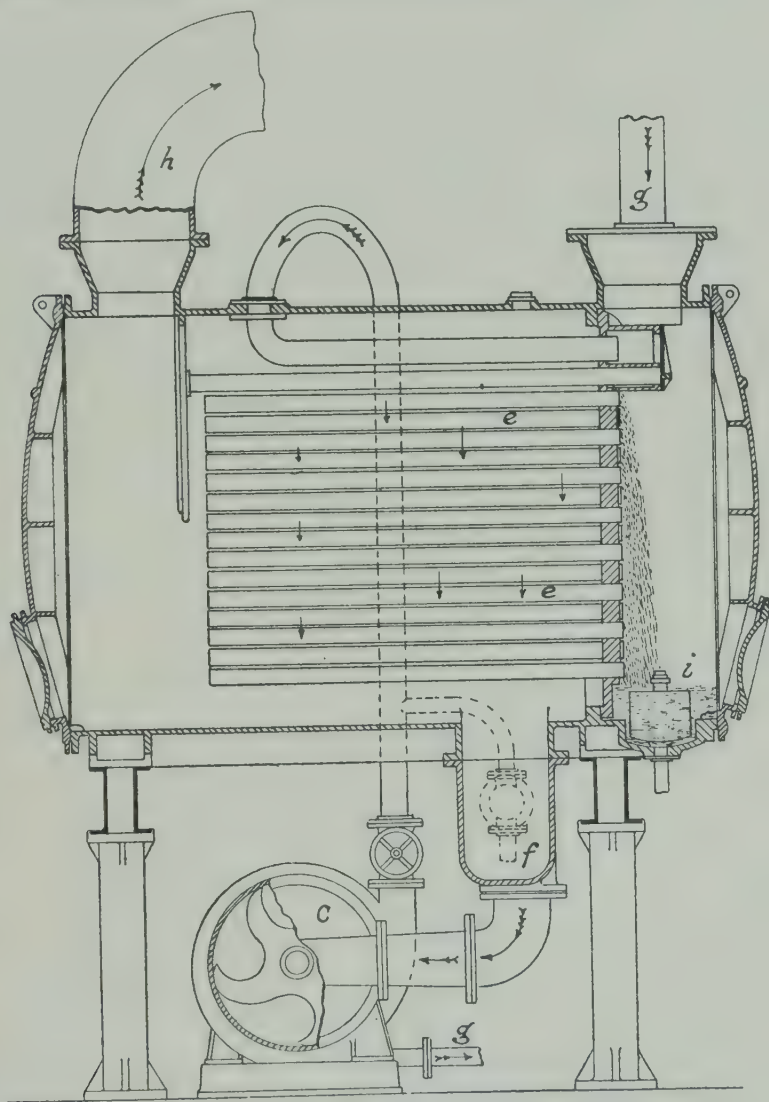


FIG. 68.

short time. The state of subdivision of the juice allows a free and easy disengagement of vapour without spurting and tends to diminish entrainment losses.

Entrainment losses in boiling are due to two distinct causes: particles of sugar may be carried over into the vapour pipes by splashing, or may be passed over by what is known as vesicular transference. Losses in splashing may be prevented by baffle plates

and save-alls (see *Fig. 58*), but such devices are of very little use against vescicular transference. By this term is meant the formation of bubbles of liquid; the tendency to so form them is greatest when the liquid is viscid, as in the last body of an evaporator. These bubbles being very light in proportion to bulk are carried forward very readily by the current of vapour. One of the best known

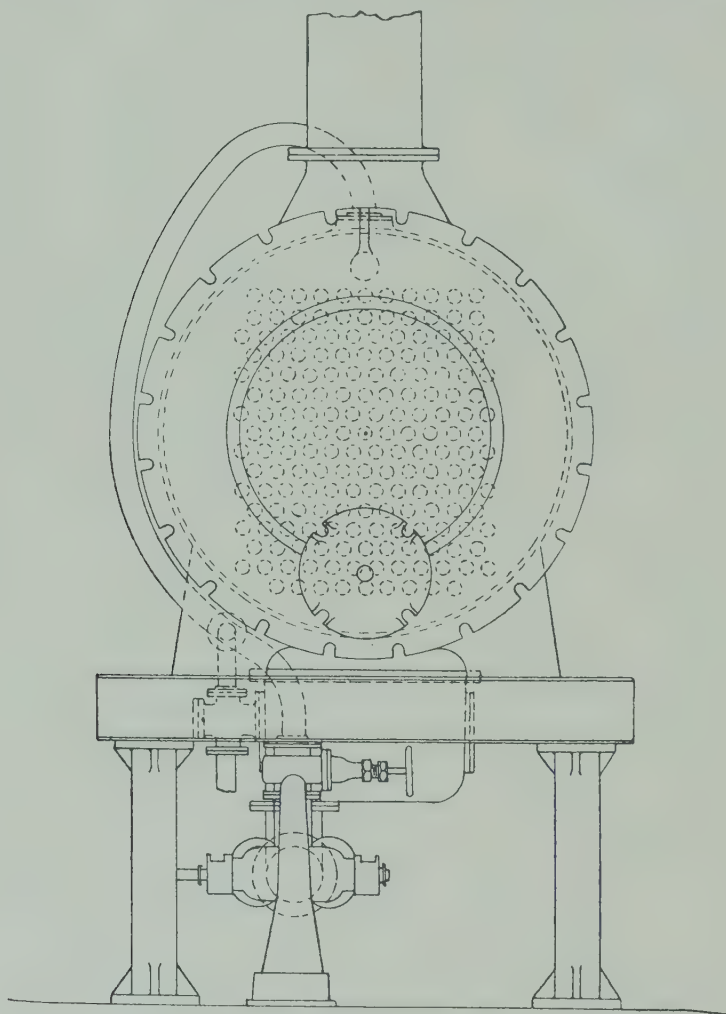


FIG. 69.

contrivances to prevent loss on this account is the *Hodek Ralentisseur** extensively used on the Continent, and also in Mauritius (*Fig. 70*). It consists of a vessel about 6 feet long and 3 feet in diameter interposed in the vapour pipe connecting any two bodies. Placed in the vessel are three perforated diaphragms, the total area of the perforations being greater than the area of the vapour pipe. The exact action of the *Hodek* is not understood. In part it may be due

* French, *Ralentir*: to slacken.

to the sudden fall in velocity, the vescicles being precipitated or perhaps burst, and again there may be some mechanical action due to the diaphragms. *Ralentisseurs* without diaphragms have also a useful effect, and are employed with the object of avoiding the injurious loss of head in the vapour due to friction.

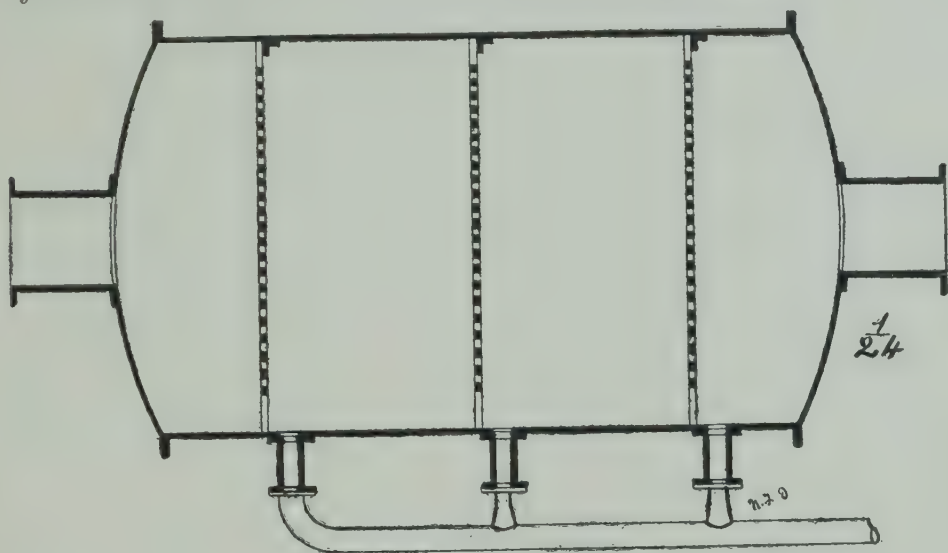


FIG. 70.

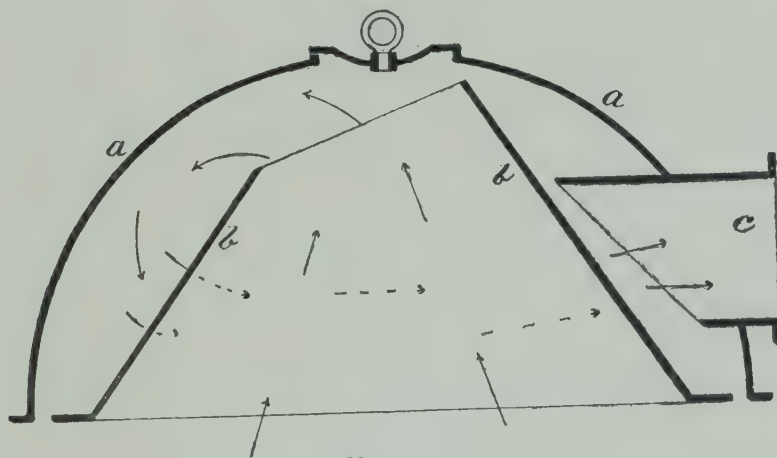


FIG. 71.

A second form of entrainment preventer, the patent of Messrs. John McNeil & Co. is shown in *Fig. 71*. Within the dome-shaped cover (*a*) of the effect or pan is arranged a conical vessel (*b*). The orifice of this funnel is pointed in the direction opposite to the pipe leading to the next effect or to the condenser. Particles of juice are projected on to the roof and thence fall on to the sides of the cone, and the vapour in its passage round the cone also deposits particles of liquid. The condenser pipe (*c*) projects inwards to prevent these particles from being swept forward with the current of vapour.

Before entering upon the calculations necessary for the design of a multiple effect, it will be convenient to mention the standards to which pressures and vacua are referred and to detail some other theoretical considerations.

The normal pressure of the atmosphere is 14.707 lbs. per square inch and it will support a column of mercury 29.92 inches high; in the metric system the corresponding measures are 1.034 kilos per square cm., and a barometric height of .760 metre. Pressures are also expressed in atmospheres and we thus have 1 lb. per square inch = 2.035 inches of mercury = .068 atmosphere. The vacuum in an effect is nearly always given in inches of mercury; thus, a vacuum of 25 inches means that the excess of atmospheric pressure over the pressure in the effect would support a column of mercury 25 inches high; hence expressed as a pressure a vacuum of 25 inches means a pressure of $29.92 - 25$ inches = 4.92 inches = 2.42 lbs. per square inch.

The *British Thermal Unit* has already been defined; the metric unit includes the kilogram and degree centigrade, the connection between the two units being that 1 *Calorie* (metric unit of heat) = 3.967 B.T.U.

The *Co-efficient of Transmission of Heat* is a factor which represents the number of units of heat which pass in one hour from a warmer to a colder material through one square foot of surface with a difference of temperature of 1° F.; the metrical units of reference are the square metre and degree centigrade, so that the metric co-efficient is 19.36 times as large as the British.

The transmission of heat is governed by the following laws:—

1. It is directly proportional to the mean difference of temperature.
2. It varies with the nature of the material through which the heat passes. The best conductors of heat are metals, silver and copper in particular; copper or brass are the two materials used in practice.
3. The co-efficient of transmission decreases with increasing thickness of metal; for copper, however, within the thicknesses employed in practice the co-efficient is sensibly constant, and even with brass 5% would be an extreme variation.
4. The co-efficient of transmission is affected by the nature of the substances on either side of the partition; thick viscid liquids as occur

in the last body of a multiple effect greatly retard the passage of heat as compared with water. In an extreme case it may be only one-fifth of what it is when dealing with water.

5. Incrustations such as occur on the tubes of a multiple effect, have an enormous and undeterminable effect in reducing the passage of heat.

6. The larger the heating surface, *i.e.*, the partition separating the substances between which a transfer of heat occurs, the less is its efficiency; that the efficiency is proportional to the square root of the surface has been established for tubes internally steam heated, and the same relation probably holds for externally heated tubes.

7. The transmission is also affected by the position of the heating surface; thus with vertical tubes the condensed water, which is formed on the surface of the tubes, flows down them and prevents intimate contact of steam and heating surface. With horizontal tubes the condensed water drops off the tubes and the latter are in general more efficient. Any form of apparatus which permits easy and rapid removal of condensed water is *per se* more efficient than one which does not fulfil those conditions.

The theory of multiple evaporation in vacuo has been elaborated by Horsin Déon, Jelinek, and others. The most complete and elegant theory is that due to Hausbrand;* in what follows the writer is indebted to all these experts and especially to the last.

It may be stated at once that it is impossible to calculate on first principles the pounds of water evaporated in each body of a multiple effect, unless the different temperatures in each body are assumed. The temperatures, however, depend on a number of factors: the temperature of the heating steam, the vacuum in the last body, the height of the liquid under treatment, &c., all of which are variable or unknown. Very considerable information can, however, be obtained on the lines below.

In a simple unexact way it is understood that a pound of steam introduced into the first body evaporates there a pound of water, the resulting steam passing on to the second body again evaporates a second pound of water and so on; but this supposition is only approximate.

* Evaporating, Condensing and Cooling Apparatus. Hausbrand. Scott, Greenwood & Co., London.

In the first instance, as the temperature at which evaporation occurs decreases, the latent heat increases, so that for this reason the steam from an earlier vessel evaporates less than its own weight of water in the succeeding one, but on the other hand the liquid entering from an earlier vessel itself suffers a fall in temperature and the heat given up can only go towards the formation of steam. Water evaporated by reason of this last cause is termed *self evaporation*. As a numerical example the following data may be taken; 100 units of water enter the first vessel and from it are evaporated 25 units of water, so that 75 units pass on to the next vessel. Let the temperature in the first vessel be 212°F. and in the second vessel be 194°F. ; the latent heats of steam at the two temperatures are 966 and 978 B.T.U. respectively. The 25 units of steam will then evaporate by their condensation $25 \times \frac{966}{978} = 24.7$ units of water. But the water in cooling down from 212°F. to 194°F. gives up $75 (212 - 194) = 1350$ units of heat; this quantity will evaporate $\frac{1350}{978} = 1.4$ units of water. This latter is the self evaporation and the total evaporation is $24.7 + 1.4 = 26.1$ units. Another cause tends to make the evaporation greater; the steam or vapour which has caused evaporation flows away, not at the temperature which it possessed when in the form of steam, but at the temperature which prevails in the lower part of the calandria where it is condensed, however; the evaporation on this score is barely appreciable.

By a system of trial and error, Hausbrand has calculated the actual evaporation in each vessel of a double, triple, and quadruple effect for a large number of differently divided temperatures, for evaporations of 90% and 75% of the original weight of the liquid, and from the results of his calculations he has demonstrated that of the total quantity of water evaporated in any vessel, that portion evaporated by heating (apart from self evaporation) is very constant and that the total evaporation in each vessel is very much of the same order.

The five conclusions drawn by Hausbrand are :—

1. The smallest amount of heating steam required to produce a certain amount of evaporation is used in all evaporators when the fall in temperature is the same in each vessel.

2. However the fall in temperature in the separate vessels be arranged, the weight of heating steam to be supplied to the first vessel always varies within very narrow limits. Thus the manner in

which the available fall in temperature is distributed amongst the separate vessels has no great influence upon the economy of steam. No considerable saving in steam can be obtained by any definite division of this fall in temperature.

3. The quantity of water to be evaporated in the first vessel is on an average of the total evaporation :—

$$\text{In the double effect } \frac{1}{2.147} = 0.466.$$

$$\text{In the triple effect } \frac{1}{3.333} = 0.300.$$

$$\text{In the quadruple effect } \frac{1}{4.626} = 0.216.$$

The extreme cases are :—

$$\text{For the double effect } 0.434 — 0.484.$$

$$\text{For the triple effect } 0.2777 — 0.3152.$$

$$\text{For the quadruple effect } 0.1926 — 0.2335.$$

4. The evaporation effected by heating* is in all cases the least in the first body, but the increase in the following vessels is not very great, at most four per cent. In the mean it may be assumed that this evaporation in the separate vessels is in the

$$\text{Double effect } 1 : 1.045.$$

$$\text{Triple effect } 1 : 1.01 : 1.04.$$

$$\text{Quadruple effect } 1 : 1.005 : 1.012 : 1.02.$$

5. The total quantity evaporated in the last vessel is

$$\text{In the double effect } 0.534.$$

$$\text{In the triple effect } 0.3734.$$

$$\text{In the quadruple effect } 0.284$$

of the total evaporation of the apparatus.

In the mean the evaporative capacity of each vessel, not including self evaporation in the vessel, but including the evaporation due to heating from self evaporation in a previous vessel, is in

$$\text{Double effect } 1 : 1.0045.$$

$$\text{Triple effect } 1 : 1.0075 : 1.138.$$

$$\text{Quadruple effect } 1 : 1.0055 : 1.109 : 1.196.$$

Hausbrand uses the figures given immediately above to calculate the relative areas of heating surface in the different vessels, provided the coefficient of transmission of heat is known in each vessel; if, for

* Steam produced by self evaporation in the second body evaporates water by heating in the third; these figures do not include water evaporated by heating on this score.

the moment, this be taken as the same for each vessel, then if equal differences of temperature are desired from vessel to vessel, this would be obtained by making the heating surfaces in the ratio given above; similarly, if the heating surfaces were made the same in all the vessels the falls in temperature would be in the same ratio.

The transmission of heat is, however, not the same for all the vessels; it decreases from vessel to vessel, due to the greater viscosity and to the incrustations being more pronounced in the later vessels.

Claassen, from actual observations in beet sugar factories, gives the following ratios for the transmission coefficient:—

Vessel.	I.	II.	III.	IV.
Double effect	1	: 0.66	..	.
Triple „	1	: 0.70	: 0.33	..
Quadruple effect	1	: 0.91	: 0.75	: 0.55

If these figures be taken as data, then to obtain the same temperature difference, the heating surfaces would be in the ratio:—

Double effect—

$$1 : \frac{1.045}{0.66} = 1 : 1.58$$

Triple effect—

$$1 : \frac{1.0075}{0.70} : \frac{1.138}{0.33} = 1 : 1.44 : 3.414$$

Quadruple effect—

$$1 : \frac{1.0055}{0.91} : \frac{1.109}{0.75} : \frac{1.196}{0.55} = 1 : 1.105 : 1.48 : 2.175$$

Now since it is only by larger differences in temperature that viscid juices are brought into violent ebullition, and since it is of great importance to maintain a rapid movement and good circulation, it is better, says Hausbrand, to have a large fall in temperature between the two last bodies, and not to aim at equalising the fall in temperature by increasing the heating surface in the later bodies.

It was, and still is, a very general rule for makers to design evaporators with heating surface increasing from vessel to vessel. Hausbrand recommends that at the very most the heating surface in the last body should be not greater than and perhaps a little smaller than in the first.

A very important factor in dealing with multiple evaporators is the evaporation per square foot of heating surface, or, in other words, the

capacity; the chief factor is the available fall in temperature from vessel to vessel, and a numerical example will best show how the available fall is less than that calculated from the pressure of heating steam and the vacuum in the last body.

Let the heating steam be at a pressure of 8 lbs. per square inch, corresponding to a temperature of 234° F., and let the pressure in the last body be 2.42 lbs. per square inch., corresponding to a vacuum of 25 ins., and to a temperature of 132° F.

Then the total fall in temperature is $234 - 132 = 102^{\circ}$ F., and the average fall from vessel to vessel is 34° F. Let the juice under treatment enter at a density of 1.0709 or 18° Balling, and leave at a density of 1.253 or 55° Balling.

Now for convenience of calculation let there be equal evaporation in each vessel, then the total evaporation per cent. by weight on original juice is

$$\frac{55 - 18}{55} \times 100 = 67.27\%$$

of which each vessel evaporates one-third or 22.42% of the juice.

Then if B. is the degree Balling of juice in the first vessel

$$\frac{B. - 18}{B.} = .2242$$

whence $B. = 23.2$, corresponding to a density of 1.093. Similarly the juice in the second vessel is found to be of density 32.6 Balling or 1.136.

These densities are correct at a temperature of 84° F. and the densities are required at the temperatures prevailing in the vessels which, assuming the fall in temperature equally divided, are 210° F., 180° F., 160° F.; the respective densities at these temperatures are 1.054, 1.106, 1.229.

Now consider the case of a vertical submerged tube apparatus with tubes four feet long, and let the level of the liquid be six inches above the level of the tube plate; the vapour formed in the tubes must, so as to disengage itself, be at a pressure equal to the pressure in the vapour space increased by the pressure due to the weight of the column of liquid. This increase in pressure varies with the place where the vapour is formed; the maximum height is four feet, the minimum six inches, the mean is twenty-seven inches.

Then since the vapour at the moment of its formation is at a greater pressure than that already formed, and since the temperature of a

boiling liquid is equal to that of the vapour which it gives off, it follows that the mean temperature of the juice in ebullition is greater than that of the vapour in the vapour space.

Again the juice is emulsioned with the vapour it gives off and this has a tendency to diminish the density of the boiling juice. Now to obtain an idea of the volume of the contained vapour, reference can be made to an article by Dessin in the *Journal des Fabricants de Sucre*. He recalls the phenomenon observed when an evaporator stops boiling, namely, that the level of the liquid falls. This fall in level, which is of the order of three inches, Dessin takes as giving the volume of the contained vapour.

Take the case of the third body of a triple, the vacuum being 25 in., the vessel 6 ft. internal diameter, the tubes 4 ft. long, 2 in. diameter, and 630 in number. The total volume of the juice is the volume of the tubes + the volume above the tube plate — the volume occupied by the vapour. We have, then, at rest

$$\begin{aligned}\text{Vol. of the tubes} &= 630 \pi \left(\frac{1}{12} \times \frac{1}{12} \times 4 \right) \text{ c. ft.} = 55.0 \\ \text{Vol. above tube plate} &= \pi \times 3 \times 3 \times \frac{1}{2} \text{ c. ft.} = 14.1 \\ &\hline &69.1\end{aligned}$$

During ebullition the total volume is that found above + that occupied by vapour = $\pi \times 3 \times 3 \times \frac{1}{4}$ c. ft. = 7.0 c. ft. The total volume during ebullition is then 76.1 c. ft.

The finally corrected densities of the juices then appear

$$\text{First vessel, } 1.054 \times \frac{69.1}{76.1} = .957$$

$$\text{Second vessel, } 1.106 \times \frac{69.1}{76.1} = 1.004$$

$$\text{Third vessel, } 1.229 \times \frac{69.1}{76.1} = 1.116$$

The vapour then in the third vessel will have to raise a column of liquid of mean height 27 in., and of density 1.116; this is equivalent to 2.20 in. of mercury or 1.09 lbs. per square inch. The vapour itself was taken at a pressure of 2.42 lbs. per square inch, so that the pressure of the vapour at the moment of its formation is $2.42 + 1.09 = 3.51$ lbs. per square inch, corresponding to a temperature of 147° F., that of the vapour was 132° F.; a difference of 15° F.

Similarly for the second body a difference of 7° F., and for the first of 4° F. are found.

The efficient fall in temperature from body to body is then

$$\frac{234 - 132 - (15 + 7 + 4)}{3} = 26^{\circ} \text{ F.}$$

or 76.5% of what would be the case if the height of juice in ebullition was zero.

To illustrate of what vital importance it is to have as great as possible a vacuum in the last body, figures are given below for an identical apparatus where the vacuum in the last body is 27 in. corresponding to a temperature of 114° F., and a pressure of 1.43 lbs. per square inch. Taking the vacua in the other two bodies as 4 in. and 17 in., the efficient fall in temperature is found to be 30.3° F., that is to say the heating surface compared with the apparatus where the vacuum in the last body is only 25 in., is 30% more valuable.

In describing the Welner-Jelinek apparatus it was stated that the height of the column of liquid was only 24 in. A calculation as above for a final 25 in. vacuum gives the efficient fall in temperature as 28° F. — 29° F., and proportionally higher for a 27 in. vacuum. It was with particular reference to this point that the Welner-Jelinek was designed.

In the film evaporators of the Lillie and Yaryan type there is no increase in pressure due to the height of the boiling column of liquid, but whereas in the latter the juice is contained in the tubes and the vapour formed can only escape at the end of a unit, this vapour must, while in the tubes, be under pressure and tend to increase the boiling point to the detriment of the efficiency of the heating surface. In the Lillie design the vapour formed is free to escape in all directions, and the juice falling in a rain or film there is no increase of temperature in the body of the liquid for the reasons detailed above, and the efficiency of the heating surface must approach the maximum value.

In a quadruple effect submerged vertical tube apparatus the efficient fall in temperature from vessel to vessel on the lines given above, works out with a 25 in. vacuum at about 14° F., and with 27 in. vacuum at about 18° F.; for a Welner-Jelinek the corresponding figures are about 16° F. and 20° F. The maximum for the two cases, there being no increase due to head of liquid under treatment, is 25° F. and 30° F. respectively.

In the majority of sugar houses the evaporation is done by triple effects, and it was supposed once that the maximum working number of effects was three, and that with four a sufficient fall in

temperature could not be obtained to allow heat to pass from condensed vapour to boiling juice. Formerly vertical apparatus were constructed with tubes even 6 ft. long, causing the efficiency of the heating surface to become very low. By reducing the length of the tubes to 3 ft. or 3 ft. 6 in., and by attending to the necessity for as low a vacuum as possible in the last body, quadruple effects using back pressure steam only are working in many sugar houses, and do not require high pressure steam at all. In some sugar houses, however, quadruples can be seen where the juice in the first vessel boils under more than atmospheric pressure. With film evaporators quadruple evaporation is general, and quintuple effects have also been constructed. Assuming a minimum fall in temperature for efficient working from vessel to vessel of 20° F., the maximum number of effects with steam at 234° F. and a final vacuum of 27 in. will be six, and this result could only be obtained with film evaporators.

It should be noticed that this increase in temperature due to height of liquid is greatest when the pressure is least; in the following table are given figures showing how this varies for different pressures, the density of juice being taken uniformly as unity:—

Mean height of column of liquid causing increase in pressure. Inches.	Vacuum in inches of mercury.					
	5	10	15	20	25	27.5
	Increase in temperature, F°.					
12	1	1	2	2	5	9
18	3.5	4	5	5.5	9	18
24	4	5	6	7	13	22
30	4.5	6	7	9	15.5	25

As the result of actual experience it has been found that in vertical submerged tube apparatus, with tubes of length from three to three and a half feet, a double effect evaporates from seven to nine, a triple effect from five to seven, and a quadruple from three to five pounds of water per square foot of heating surface per hour with steam at five pounds per square inch pressure. As illustrating what enormous differences in evaporation per square foot may be obtained the following tests of a submerged tube apparatus and a Lillie film evaporator, both making distilled water, may be quoted. They are taken from

The Journal of the American Society of Naval Engineers, Vol. X., pp. 597-793; Vol. XI., p. 889; Vol. XII., page 85.

	Type of Plant:	
	Lillie Triple Film.	Submerged Tube Triple.
Total heating surface	1,827 sq. ft. ..	3,396 sq. ft.
Heating surface in evaporators ...	1,320 ,, ..	3,840 ,,
Heating surface in heaters	507 ,, ..	156 ,,
Pressure of steam to first effect—per square inch.	10·8 lbs. ..	64 lbs.
Gallons of water distilled per 24 hours	91,403	58,897
Gallons of water distilled per square foot per 24 hours	50 ..	14·75
Pounds of water distilled per square foot per hour	17·31 ..	5·11
Efficiency of heating surface	3·4 ..	1·0

The passage of vapour from the vapour space of one body to the steam drum of the next takes place under a slight difference of pressure; this pressure amounts to 0·3 lb. per square inch, corresponding to a difference in temperature of about 1° F. To calculate from these data the velocity of a gas leaving an orifice requires the use of higher mathematics, which it would serve no useful purpose to reproduce here; under the conditions named, the velocity of a gas is of the order 200 ft. per second; such a velocity is not obtained in evaporators because of the friction of the gas on the walls of the pipes, abrupt changes in direction, especially those due to baffle plates and save-alls, and also to condensation of a part of the vapour. For steam and vapour pipes it is customary to allow a velocity of 100 ft. per second, and for the vapour leaving the last body a velocity of 150 ft. per second; if velocities higher than these obtain, a very considerable fall in the temperature of the vapour occurs, reducing the efficiency of the apparatus. As an example of this and other calculations, the case of a triple effect with 4,000 sq. ft. heating surface, evaporating 6 lbs. water per square foot per hour, or 2·22 lbs. per second per vessel, is taken.

Steam Pipe.—Taking the temperature of the heating steam to be 234° F., 1lb. will occupy 17·83 c.ft., and allowing 1lb. steam to evaporate 2·90lbs. water, 2·31lbs. (= 41·19 c.ft.) will be required per second. At a velocity of 100ft. per second the area of the pipe must be 4119 square feet, corresponding to a diameter of 8½ in.

Vapour Pipes.—Taking the temperature of the vapour from the first vessels as 206° F., 1lb. occupies 29.6 c.ft.; at a velocity of 100ft. per second, the area of the pipe must be .657 sq. ft., corresponding to a diameter of 11in. The temperature of the vapour from the second vessel being taken as 177° F. will occupy 53.4 c.ft. per lb., and under the same velocity demands a vapour pipe 15in. in diameter. Finally, for the pipe leading to the condenser, allowing here a velocity of 150ft. per second, a diameter of 21ins. is obtained; 1lb. of vapour at 132° F. occupying 152.4 c.ft.

Injection Water.—Assuming the vacuum in the condenser is 27.5ins., the corresponding temperature is 104° F., and the temperature of vapour given off in the last body may be taken as 134° F. At this temperature the latent heat of steam is 1022 B.T.U., so that in condensing 1lb. of vapour at 134° F. and cooling to 104° F. (corresponding to a vacuum of 27.5 inches) 1052 B.T.U. are absorbed. Allowing the injection water to be of temperature 84° F., each pound of water absorbs 20 B.T.U., so that 52.6lbs. water per pound of vapour will be required, and to obtain this result at least 10% or 20% more water must be admitted.

It is, however, only in exceptional cases that so large an amount of injection water is admitted, and the temperature of the discharge is more frequently 115° F. to 120° F. If the temperature of injection water be again taken as 84° F., to obtain discharge water at this temperature, the quantity of injection water required is only thirty times as much as the vapour to be condensed, and this is the quantity usually allowed for in design. The objection to admitting the larger quantities is the accompanying increase in size of the pump, but the economy is only effected at the expense of the vacuum in the last body, and consequently at the efficiency of the heating surface as a whole.

The size of the injection pipe to deliver a definite quantity of water depends on the head, the length, and diameter of the pipe, and the number of bends. The theory of the flow of water in pipes is too complex to be reproduced here, but a table is given below showing the velocity of water at exit from pipes of diameter 4ins. to 12ins., for lengths of from 40ft. to 100ft., and with one, two, or three right angle bends. The table has been calculated from the latest formulae, and a constant head of 16ft. has been assumed corresponding to a 25in. vacuum, and a height of 12ft. of entry of injection water above level in well.

Table giving Velocity of Water at Exit under a Head of 16ft. for different Conditions of Pipe.

No. of Bends.	Length of Pipe. Feet.	DIAMETER OF PIPE. INCHES.								
		4	5	6	7	8	9	10	11	12
		VELOCITY OF FLOW AT EXIT : FEET PER SECOND.								
1	40	13.9	15.0	15.8	16.3	16.9	17.3	17.6	17.9	18.1
2	40	13.7	14.7	15.5	16.0	16.5	16.9	17.3	17.5	17.6
3	40	13.5	14.5	15.2	15.7	16.2	16.5	16.7	17.1	17.3
1	60	12.3	13.4	14.4	14.9	15.7	16.0	16.4	16.7	16.9
2	60	12.1	13.2	14.0	14.6	15.4	15.7	16.0	16.3	16.5
3	60	12.0	13.0	13.8	14.3	15.1	15.4	15.7	16.0	16.3
1	80	11.2	12.2	13.1	13.7	14.4	15.0	15.4	15.7	16.0
2	80	11.0	12.1	12.9	13.5	14.1	14.7	15.1	15.4	15.7
3	80	10.9	11.9	12.8	13.4	14.0	14.3	14.7	15.1	15.4
1	100	10.2	10.6	11.5	12.1	12.9	13.4	13.7	13.9	14.4
2	100	10.1	10.5	11.4	12.0	12.8	13.1	13.5	13.7	14.2
3	100	10.0	10.4	11.3	11.9	12.7	12.9	13.4	13.6	14.1

The calculation of the volume of gases removed by the pump is so unsatisfactory as not to repay study. A certain quantity of air enters the apparatus dissolved in the juice, which is released on boiling, and the juice itself in treatment forms a certain amount of gas; air, too, will leak into the apparatus, and some will be introduced dissolved in the injection water. Experimental data are so incomplete on these points that they can give little or no help to practice.

The loss of heat in multiple evaporators is greater than would be calculated at first sight, for heat lost by radiation in the first body is, in a triple effect, in reality trebly lost, and that lost in the second body doubly lost. A calculation of loss of heat in this way is appended. In the case of a triple effect evaporator with each vessel 6ft. in diameter and 12ft. high, the exposed area from which radiation takes place is in each body, including the vapour pipes, approximately 300 square feet. The temperatures existing in each body may be taken as 203° F., 180° F., 130° F., and the external atmosphere as 84° F.; the differences in temperature under which loss of heat from radiation takes place are then 119° F., 96° F., and 46° F.

According to experiments quoted by Box (*Treatise on Heat*, p. 235), with a difference of temperature of 152° F. a horizontal cast-iron pipe lost 294.9 B.T.U. per square foot per hour. The loss of heat from the triple then is per hour, if the triple is not lagged:—

$$\text{First body} \quad \dots \quad 3 \times 300 \times 294.9 \times \frac{119}{152} = 176,072 \text{ B.T.U.}$$

$$\text{Second body} \quad \dots \quad 2 \times 300 \times 294.9 \times \frac{96}{152} = 94,694 \text{ B.T.U.}$$

$$\text{Third body} \quad \dots \quad 300 \times 294.9 \times \frac{46}{152} = 22,687 \text{ B.T.U.}$$

$$\text{Total} \quad \dots \quad \dots \quad 293,453 \text{ B.T.U.}$$

equivalent to about 250 lbs. of steam.

A triple of such a size will have approximately 3,000 sq. ft. heating surface, and will utilise 6,000 lbs. steam per hour. The loss then is, for an unlagged triple, about 4%. By lagging with suitable material the loss can be reduced to at least one-quarter of what it is with a naked pipe, so that an evaporator may roughly be estimated as losing by radiation 1% of the heat supplied. It is not only the loss of heat that is of importance in a badly-protected evaporator, but any fall in temperature of heating and vapour will tend to lower the efficiency of the apparatus as regards evaporation per unit of heating surface.

The condensers which find use in forming and maintaining the vacuum in the last body of a multiple evaporator, may be classed either as *jet* or *surface* condensers, or again as *dry* or *wet* condensers. Surface condensation is now only employed when the vapour from the last body is used to heat the juice coming from the mills; in these apparatuses the juice circulates inside the tubes, the vapour being outside; in no case will the juice itself be sufficient to condense all the vapour, and the portion uncondensed is condensed by the usual method described below. By utilising the vapour from the last body in this way a certain economy is obtained, but these heaters have to be very carefully arranged so as not to obstruct the passage of the vapour and thus diminish the capacity of the evaporator. The temperature to which the juice can be heated depends, of course, on the degree of vacuum in the last body; a 25 in. vacuum corresponds to a temperature of 133° F., and with this vacuum that is the highest temperature to which the juice can be raised. A numerical example will make the economy of these apparatuses clear.

Let there be evaporated under a 25 in. vacuum in the last body of a multiple effect 233 lbs. water per 1000 lbs. juice; the condensation of

this quantity of vapour will afford 238,126 B.T.U. Now, taking the specific heat of juice as 0.9 and the initial temperature as 84° F., to raise 1,000 lbs. from 84° F. to 133° F° requires 44,100 B.T.U., so that 18.5% of the vapour can be condensed by the juice. The megass corresponding to 1000 lbs. of juice will roughly afford 1,000,000 B.T.U., so that the saving calculated on the megass available for fuel will be between 4% and 5%.

The injection condenser usually employed to condense the vapours given off from the last body of an effect, consists essentially of a cast-iron cylindrical body connected by a pipe, called the vapour pipe, to the vapour space of the effect, and also by a second pipe to the suction of an air pump; a third pipe called the injection pipe leads water from a well to the condenser. A vacuum being formed in the condenser by means of the pump, water enters the condenser under the influence of atmospheric pressure. The vapour given off from the effect meeting the stream of cold water is condensed, and the vacuum maintained; the condenser water and incondensable gases pass to the pump and are there discharged.

As the efficiency of a multiple effect depends very largely on the vacuum in the last body, and this in turn on the completeness of the condensation, attention to the design of the condenser is important. The commonest method of distributing the injection water within the condenser is by means of a rose; with this arrangement there is liability of the holes becoming choked, especially when any but the cleanest water is available. Better arrangements are shown in *Figs. 72 and 73*. In the form shown in *Fig. 72* the vapour enters at *a* and the injection water at *b*; the whole then follows the path indicated by the arrows through the apertures in the plates, and is discharged at *d* to the air pump. In the form shown in *Fig. 73* the injection water enters at *b*, overflows over a series of rings and discs in a fine shower, meeting the vapour which moves in the opposite direction forming what is known as a counter-current condenser; as shown this form is applied to what is termed the *dry vacuum*. The method of this form will be readily understood on referring to *Fig. 73*; *a* is a pipe more than 33ft. high with its lower end immersed in a tank of water; the atmospheric pressure will support a column of water 33ft. high, and above this will be a vacuum. Into the condenser water is pumped through the pipe *b*; this water overflowing at *e* meets the vapour from the effect conducted through the pipe *d*. The steam is condensed, and, together with the injection water, discharges

itself on to the surface of the column *a*, and is eventually discharged into the tank *f*. The incondensible gases are drawn off by an air pump through *e*.

Each of these systems of evaporation has its advantages. A more complete vacuum can be obtained with the dry condenser, but two pumps are required. With large plants, say, those of 5000 square feet heating surface and over, the wet air pump becomes of inconvenient size, and for such plants the dry system is to be recommended.

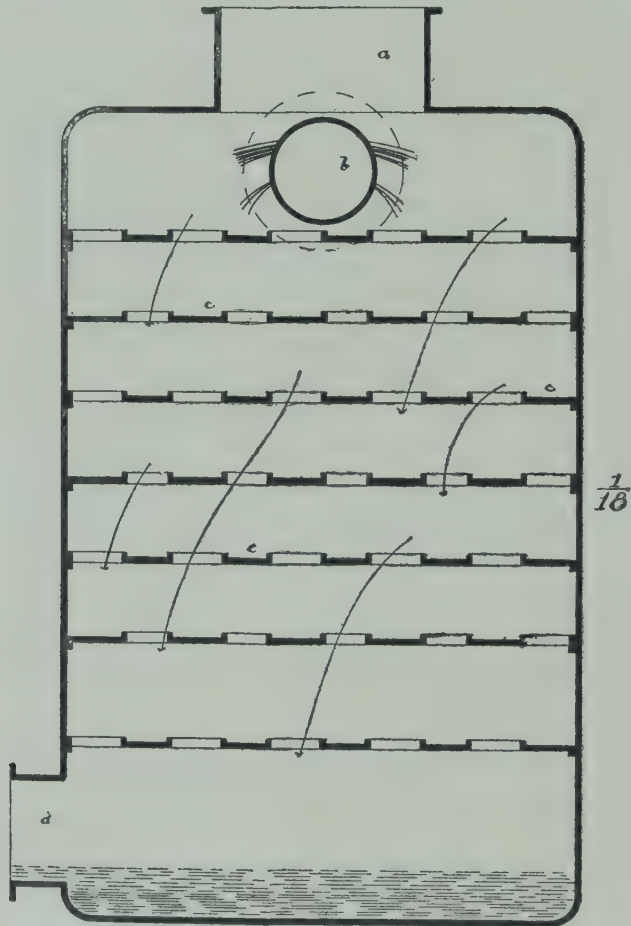


FIG. 72.

It is impossible to calculate with any satisfaction from first principles what should be the size of condensers; Jelinek recommends them to be not less than 1.5, and Horsin Déon from 2.5 to 3 times the volume of the air pump.

In beet factories of late years a development of the multiple evaporator has taken place, resulting in further heat economies. Steam is taken from a vessel—generally the first—of the evaporator to do other work in the factory, such as heating the diffusion juice or

for use in the carbonating tanks. The economy of the process, which is not quite self-evident, is shown in the following example:—

To heat a certain quantity of juice 5 units of steam are required, which are taken direct from boilers; at the same time the quadruple evaporates 100 units of water with a consumption of 25 units of steam, the evaporation being the same in each vessel, 25 units. The arrangements are altered, and the juice heated by 5 units of

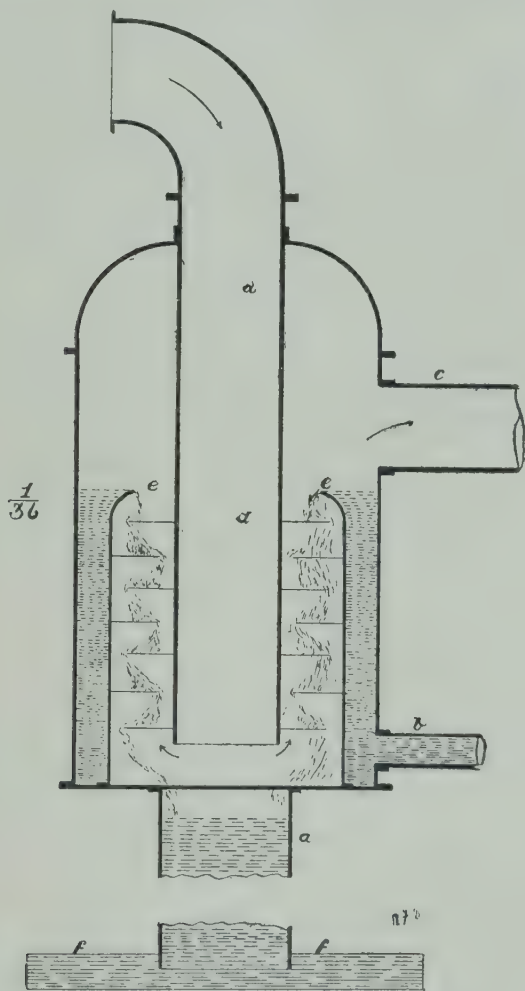


FIG. 73.

steam taken from the first vessel. In order to obtain these extra 5 units for heating, the amounts evaporated in each vessel must be altered; let the last three evaporate each a unit, then the first will evaporate $a + 5$ units, so that $4a + 5 = 100$ and $a = 23.75$. The first vessel then evaporates 28.75 units, of which 5 are used to heat the juice, and 23.75 pass on to the second vessel. The total steam now used is then 28.75 units, whereas before it was 30 units.

In beet factories steam from both first and second bodies of the quadruple is used ; that from the second is used to heat diffusion and first carbonatation juices where temperatures less than 212° F. are desired, that from the first being utilised in boiling the juice in the second carbonatation.

Where this system is adopted, the proportions of the heating surfaces have to be carefully calculated ; they have of course to be much larger than when heating with direct steam, a proceeding entailing greater initial expense ; where, as is sometimes the case, all the back pressure cannot be used up, this economy is not applicable. For use in cane sugar factories the steam from the first body must be at a temperature greater than 212° F., *i.e.*, the first body must be boiled under pressure, a process objected to by some authorities. The systematic utilisation of heat under this system, due also to Rillieux, has reduced the consumption of coal in beet factories to as low as 6% on the weight of the beets.

For general convenience the uses of pumps in the sugar factory are briefly discussed here.

For elevating the juice, duplex pumps of the Worthington pattern are very generally used, and leave little to be desired. Pulsometers are also frequently met with, and in a considerable number of plants the juice is elevated by a pump driven off the cane engine.

For elevating molasses rotary pumps driven off any convenient shafting are generally employed ; plunger and centrifugal pumps are also used. For elevating after masse-cuite, chain pumps are common. Compressed air forms perhaps the cleanest and best way of conveying masse-cuites of all kinds.

For forcing scums through filter-presses pumps or montjus are used, the former being preferable. The pumps used are generally duplex pumps, and by a simple arrangement are automatic, stopping when the pressure in the press which they are filling reaches a certain limit ; a small pipe coming from the air vessel of the pump communicates whatever pressure there is in the air vessel to an arrangement which controls the steam valve ; when the pressure reaches a limit which can be regulated the steam valve is closed, and the pump stops working. When communication with the filled press is cut off, and the pump connected on to the next press to be filled the pressure is relieved, and the pump automatically starts working ; several patented

forms, all involving the control of the steam valve by the pressure in air chamber, are on the market.

For circulating juice through the multiple effects, and for withdrawing condensed water from the calandrias, duplex pumps of the Worthington pattern are often used. The Lillie evaporators are however fitted with centrifugal pumps all worked off one line of shafting. For withdrawing the concentrated syrup from the last body a plunger pump worked off the air pump is generally used.

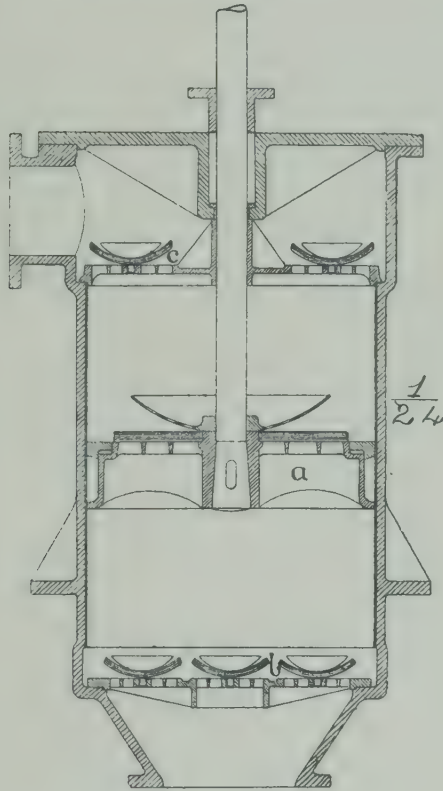


FIG. 74.

The pumps of special interest to the sugar maker are those employed to create and maintain the vacuum. They fall into two main classes—dry and wet vacuum pumps; the latter may again be divided into horizontal and vertical pumps, or into piston and torpedo plunger pumps.

In *Fig. 74* is given a sectional view of a vertical pump. At *a* is shown the piston or bucket; the foot or suction valves are shown at *b* and the discharge valves at *c*. These pumps are usually worked in pairs off a beam engine and are only to be found in antiquated factories as a general rule; as many as six or eight pumps may be

worked off one beam, the whole of the pumping plant being dependent on one engine. Although this system requires but one cylinder and economises labour and power, yet a small mishap may necessitate the stopping of the whole factory.

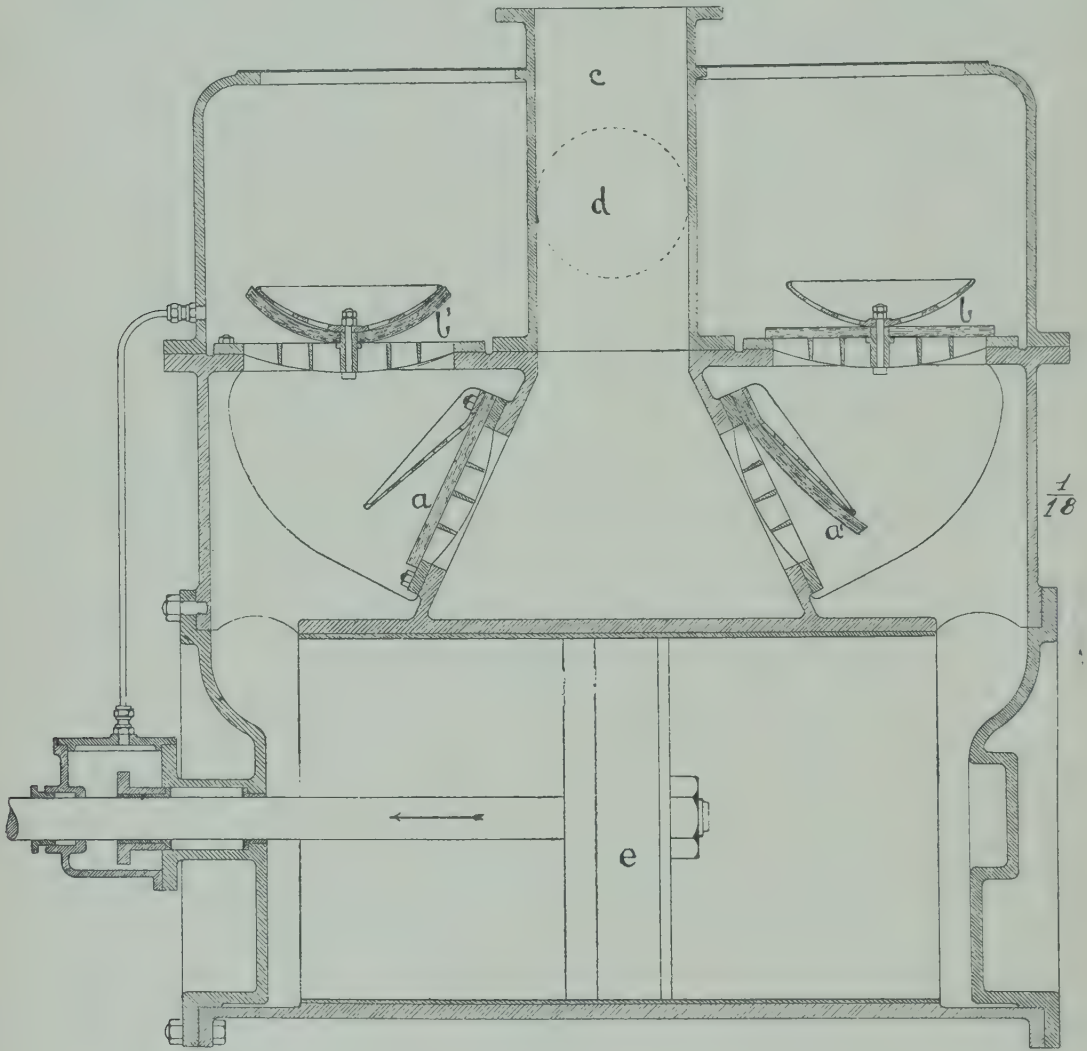


FIG. 75.

In *Fig. 75* is shown a type of horizontal bucket or piston pump; the condenser water flows from the condenser by the pipe *c* into the body of the pump; the piston or bucket *e* moving from right to left forms a vacuum behind it, the valve *a'* opens and water enters and fills the space behind the bucket (*i.e.*, to the right), at the same time the water in front of the bucket is discharged through the valve *b'*, the valves *a* and *b* being closed; on the return stroke the valves *a* and *b* are opened, *a'* and *b'* being closed. The water is discharged by the pipe *d* into the main factory sewer, the valves shown at *b* and *b'* are

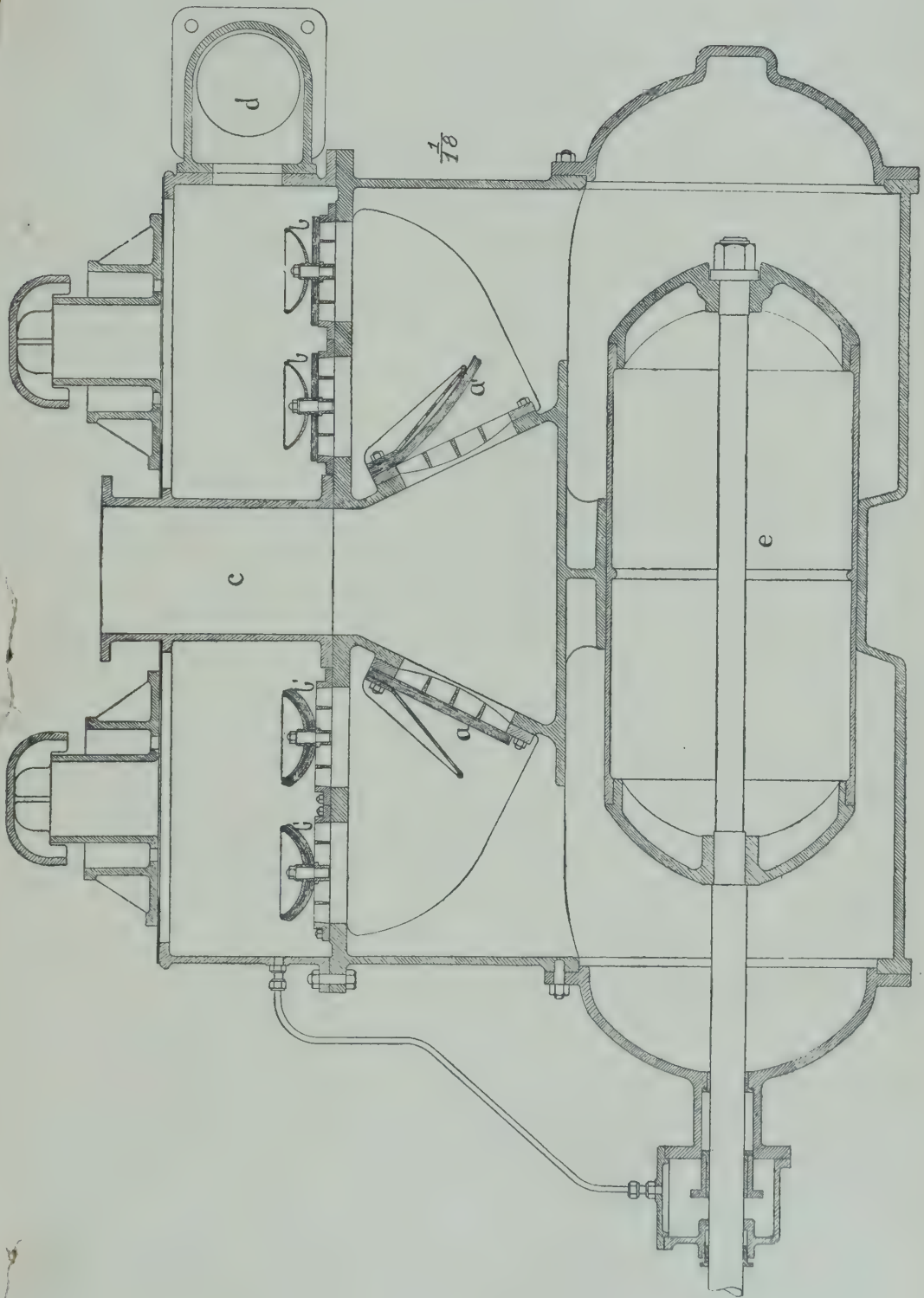


FIG. 76.

indiarubber disc valves resting on a perforated iron or brass seat known as the valve seating. The valves shown at *a* and *a'* are clack valves working on a hinge, but in modern pumps both suction and discharge valves are disc valves as at *b* and *b'*. In *Fig. 76* is shown a type known as a torpedo pump, the lettering being the same as in the previous figure. In both instances the piston rod of the pump plunger is connected in the same horizontal line with the piston rod of the steam cylinder, the pump and engine being on the same

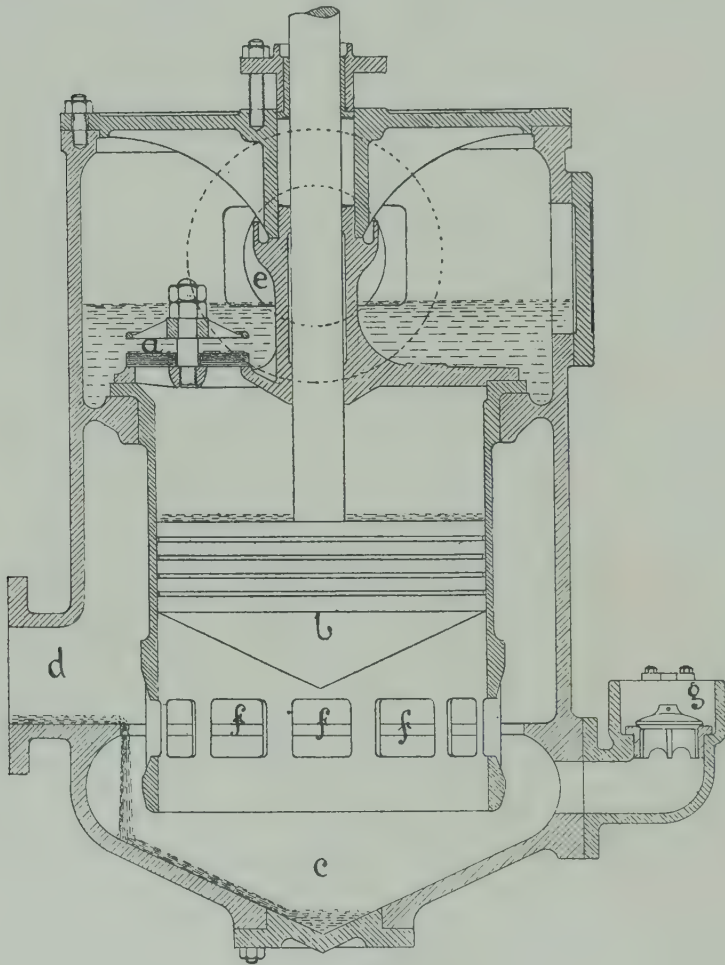


FIG. 77.

foundation. These pumps should never be worked at a speed greater than forty revolutions per minute, as it is important for the good working of the pump that the air drawn in be expelled as completely as possible; this can only happen when the air is allowed to pass through the water, then expelled followed by the water. If the pump works at a high speed the water is agitated, air cannot pass through

and both are expelled together, and more air is left in the barrel than would be the case at a lower speed.

A wet vacuum pump which has lately been extensively installed is the *Edwards' patent pump*, which allows the air to naturally pass through the water instead of being churned up with it, as is the case with the usual type of vacuum pump. This pump is shown in section in *Fig. 77*; it is a vertical single-acting pump and differs essentially from all other pumps in having no suction valves: in *Fig. 77* water from the condenser flows by way of *d* into the reservoir *c*; the conical bucket *b* on the down stroke forces the water up into the barrel of the

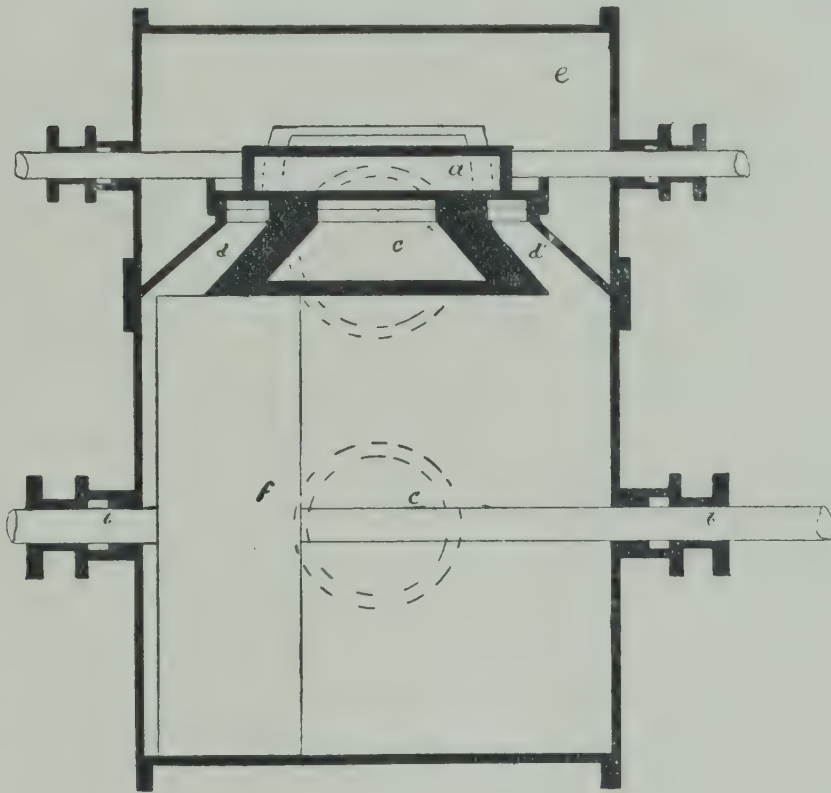


FIG. 78.

pump; as soon as the bucket rises the entry of water by way of *d* is closed until the bucket has passed and the water which has been projected into the barrel is lifted and discharged through the valves at *a* passing away at *e*: at *g* is shown a relief valve. In this pump the incondensable gases are free to escape to the space above the water; the pump is so designed that clearance is reduced to a minimum. These pumps are often arranged double or treble barrelled so that the action is practically continuous. A vacuum higher than that given by older forms of pumps is claimed for this patent.

In *Fig. 78* is given a sectional view of an old type of a dry vacuum pump. It consists of a metallic piston f driven directly by a horizontal engine; in the position shown in the drawing, the piston having moved from left to right the air is sucked through c^1 and arrives in the cylinder by way of d^1 ; the air already in the cylinder is expelled through d , thence into e and finally discharged through the pipe c . It will be seen that in the working of a pump of this type at each stroke a certain amount of air is left in the cylinder; a cushion of air is necessary to break the force of the stroke and this air being under pressure the pump does not suck until the pressure behind the piston is the same as that in the space which is being exhausted. To overcome this difficulty other forms of slide valve air pumps known as pressure equalising or compensating pumps have been devised. In *Fig. 79* is given a sectional view of the form adopted by the German firm of Wegelin & Hübner. There are three valves a , b and c , known as the distributing, equalising and delivery valves; the valve a is designed to allow the air to enter or depart and to connect the suction or discharge to the pan or atmosphere; the delivery valve c on the valve a is for the escape of air and to prevent air returning to the pump; the equalising valve b is for the purpose of connecting the channels d when the piston is at the end of the stroke; when the piston is at the end of a stroke the valve a is nearly central and the discharge and suction ports are closed; at this moment the equalising valve b makes communication between the two faces of the piston by means of the channel d and equalises the pressure on both sides of the piston; the valve b now closes and a opens, and as the piston moves from right to left air is drawn into the vacuum; the equalising valve b remains closed and the suction and delivery ports open; at the end of the stroke the valve a is again nearly central and the process described above repeats itself. Various other forms of slide valve pumps with pressure equalising arrangements are made, all of which depend on the same principle, establishing communication between the two faces of the piston at the end of a stroke. The establishment of the principles under which these pumps work demands the use of higher mathematics; if pumps could be made with no clearances or dead spaces there would be no necessity for equalising the pressure and the smaller the dead spaces the less the advantage of equalisation. A modern well designed pump of this class will work with an efficiency up to 95% and give a vacuum of from 28 to 29 inches dependent on the height of the barometer. The pumps used in the carbonatation

process for forcing the carbon dioxide gas into the saturation tanks are essentially similar in principle to those described above.

For pumps employed to maintain the vacuum in condensing engines it has been found that a displacement four to five times the volume of

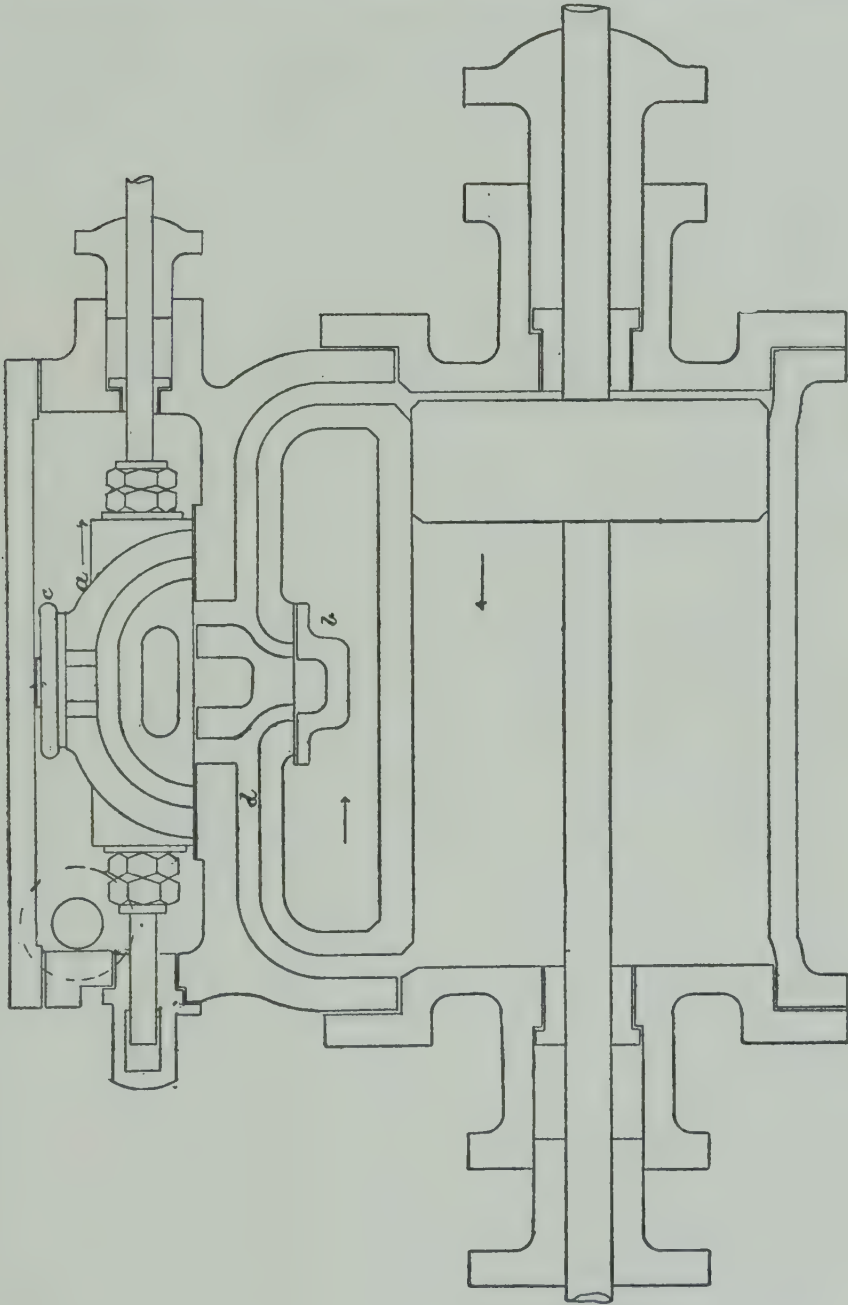


FIG. 79.

water to be discharged is sufficient; for wet vacuum pumps in connection with evaporators this allowance is insufficient and a displacement of ten times the volume of water to be discharged is

necessary. Jelinek gives as an empirical rule that for every kilogram of vapour to be condensed per minute the piston should travel through 0·3 c. metre; in English units this is 4·8 c. ft. per lb. of vapour and as Jelinek's calculation refers to European conditions with injection water at about 40° F., this allowance should be increased for tropical conditions up to 6 c. ft.; taking the injection water as 40 times the vapour to be condensed and allowing the pump to make 80 strokes per minute, an empirical rule which allows 3·2 c. ft. per stroke per 1,000 gallons of juice per hour in a triple, 1,333 in a quadruple and 275 gallons of syrup in a pan is obtained. Practice has shown that it is necessary to give the same dimensions to a dry as to a wet vacuum pump for equal capacities.

Although only indirectly connected with evaporation, the question of scale may be touched on here. Three classes of scale each demanding a different treatment are met with. The first consisting mainly of silicates can be removed by boiling with caustic soda; the second class consisting of phosphate of lime is best treated with hydrochloric acid. The most difficult scale to remove is sulphate of lime; the best method is to boil first with carbonate of soda and afterwards with hydrochloric acid. Analyses of the scale of a triple due to H. Pellet are given below:—

	First body.	Second body.	Third body.
Water and organic matter ..	29·80	26·70	18·60
Silica	0·40	23·40	69·80
Iron and alumina	3·80	9·98	2·80
Lime	46·30	25·80	0·80
Magnesia	1·36	0·81	1·08
Phosphoric acid.. .. .	17·10	11·70	Trace.
Sulphuric acid	0·00	0·00	Trace.
Copper	Trace.	Trace.	Trace.
Undetermined	1·24	1·61	0·92

Experimental trials of evaporators have for their object the localisation of faults with special reference to the cause of inefficiency whether due to bad circulation, constricted vapour pipes, or bad distribution of heating surface. The chief points to be determined are the evaporation per square foot in each body with which is connected the transmission co-efficient introducing the heat transferred per unit of area and per unit of temperature difference. To obtain the weight of liquid treated, systematic measurements of the

initial and final density of the juice must be made together with a measurement of the quantity of one of them; the evaporation in each vessel can be obtained by systematically sampling and observing the density of the partially concentrated juice on its way from one vessel to the following one; in this way the evaporation per unit of area in each body can be obtained; by observing the temperature of the juice in the calandria and of the vapour in the vapour space of the immediately preceding body, the temperature difference under which the passage of heat takes place is observed. The heat efficiency is obtained by measuring and taking the temperature of the condensed water from the first body and observing the average pressure of steam supplied. It is, of course, essential if the efficient fall in temperature from vessel to vessel be desired that the mean temperature of the boiling mass be obtained; to do this would require a thermometer or thalpotassimeter with the butt or rod immersed in the centre of the boiling mass. As this would in many cases be infeasible, the mean temperature of the boiling juice can be calculated from the observed pressure in the vapour space on the lines already indicated above.

In the following table are collected such data concerning the properties of saturated steam as will be required in a sugar house and in the calculations relating to boiler trials, evaporator trials and the theory of multiple evaporation. The data for pressures less than one atmosphere have been calculated by the writer, the remainder are taken from Fairbairn's Tables published in all text books on steam. The general formulae for the calculation are as below:—

P = absolute pressure in lbs. per square inch; p = pressure in inches of mercury. T = temperature Fahrenheit; U = total heat of evaporation; L = Latent heat of steam; V = volume of one pound of steam in cubic feet.

$$P \times V \cdot 0355 = p.$$

$$U = 1082 + \cdot 305 T.$$

$$L = 1118 - \cdot 718 T.$$

$$T = \frac{2938 \cdot 16}{6 \cdot 19935 - \log. P} - 371 \cdot 85.$$

$$\log. 62 \cdot 11 V = 4 \cdot 3135 - \cdot 941 \log. P.$$

TABLE GIVING THE PROPERTIES OF SATURATED STEAM.

P.	p.	T.	U.	L.	V.
·491	1	77·9	1107	1062	646
·982	2	101·3	1113	1045	336
1·473	3	115·3	1117	1035	240
1·964	4	125·6	1120	1028	175
2·455	5	133·4	1123	1022	142
2·946	6	140·8	1125	1017	119
3·437	7	146·9	1127	1012·5	103
3·928	8	152·3	1128·5	1008·5	90
4·419	9	157·1	1130	1005	82
4·910	10	161·6	1131	1002	74
5·401	11	168·6	1133	999	68
5·892	12	169·3	1134	996·5	62
6·383	13	172·8	1135	994	58
6·874	14	176·1	1136	992	53
7·365	15	179·1	1137	989·5	50
7·856	16	182·0	1138	987	47
8·347	17	184·9	1138·5	985	45
8·838	18	187·6	1139	983	42
9·329	19	190·0	1140	981·5	40
9·820	20	192·3	1141	980	39
10·311	21	194·6	1141·5	978·5	37
10·802	22	196·8	1142	976·5	35
11·293	23	199·0	1143	975	34
11·784	24	201·0	1143·5	973·5	32
12·275	25	203·0	1144	972	31
12·766	26	205·0	1144·5	971	30
13·257	27	206·8	1145	970	29
13·748	28	208·6	1146	968·5	28
14·239	29	210·4	1146·5	967	27
14·707	29·92	212·0	1147	966	27
15	30·50	213	1147·5	965	26
16	32·57	217	1148	963	25
17	34·60	220	1149	961	23
18	36·64	223	1150	959	22
19	38·67	226	1151	958	21
20	40·71	228	1152	956	20
21	42·78	231	1153	953	19
22	44·82	234	1153·5	951	18
23	46·85	236	1154	950	17
24	48·89	238	1155	948	16·5
25	50·93	240	1156	946	16

TABLE GIVING THE PROPERTIES OF SATURATED STEAM.

P.	p.	T.	U.	L.	V.
60	122·23	293	1171·5	909·5	6·9
61	124·27	294	1171·8	909	6·8
62	126·30	295	1172	908	6·7
63	128·34	296	1172·5	907	6·6
64	130·38	297	1172·8	906·5	6·5
65	132·42	298	1173	906	6·4
66	134·45	299	1173·5	905	6·3
67	136·49	300	1173·8	904	6·2
68	138·53	301	1174	903	6·1
69	140·36	302	1174·5	902	6·0
70	142·60	303	1174·8	901	5·95
71	144·64	304	1175	900·5	5·90
72	146·68	305	1175·5	900	5·81
73	148·72	306	1175·8	899·5	5·73
74	150·75	307	1176	899	5·66
75	152·79	308	1176·5	898	5·60
76	154·83	309	1176·8	897·5	5·52
77	156·86	310	1177	897	5·45
78	158·90	310·2	1177·2	896·5	5·40
79	160·94	311	1177·6	896	5·32
80	162·98	312	1177·8	895	5·26
81	165·01	313	1178	894	5·21
82	167·05	314	1178·2	893	5·15
83	169·09	315	1178·6	892·5	5·10
84	171·12	316	1178·8	892	5·03
85	173·16	316·2	1179·2	891	4·98
86	175·20	317	1179·6	890·5	4·93
87	177·24	318	1179·8	889	4·88
88	179·27	319	1180	888·6	4·82
89	181·31	320	1180·2	888·2	4·78
90	183·35	320·2	1180·5	888	4·73
91	185·38	321	1180·7	887·5	4·68
92	187·42	322	1180·9	887	4·63
93	189·46	323	1181	886·6	4·59
94	191·50	323·3	1181·2	886	4·54
95	193·53	324	1181·5	885·7	4·50
96	195·57	325	1181·7	885·3	4·46
97	197·61	326	1181·9	885	4·42
98	199·65	327	1182	884·6	4·38
99	201·68	327·3	1182·2	884	4·34
100	203·72	328	1182·5	883·7	4·30

TABLE GIVING THE PERCENTAGES BY WEIGHT, PER CENT, ON ORIGINAL JUICE EVAPORATED BETWEEN
DIFFERENT DEGREES BRIX OR BEAUMÉ.

INITIAL DENSITY—DEGREE BRIX IN UPPER, DEGREE BEAUMÉ IN LOWER LINE.																	
Final Density Degree Brix.	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
	5·7	6·2	6·8	7·4	7·9	8·5	9·0	9·6	10·1	10·7	11·3	11·8	12·4	13·0	13·5	14·1	
35	71·43	68·57	65·71	62·86	60·00	57·14	54·29	51·43	48·87	45·71	42·86	40·00	37·15	34·29	31·43	28·57	
36	72·33	69·45	66·68	63·90	61·11	58·33	55·56	52·78	50·00	47·23	44·45	41·67	38·90	36·12	33·34	30·56	
37	73·00	70·27	67·57	64·86	62·16	59·46	56·75	54·05	51·35	48·65	45·95	43·23	40·53	38·13	35·13	32·42	
38	73·70	71·07	68·44	65·81	63·17	60·52	57·89	55·26	52·63	50·00	47·37	44·74	42·11	39·48	36·85	34·22	
39	74·36	71·79	69·23	66·66	64·10	61·54	58·97	56·41	53·81	51·28	48·72	46·16	43·60	41·03	38·47	35·90	
40	75·00	72·50	70·00	67·50	65·00	62·50	60·00	57·50	55·00	52·50	50·00	47·50	45·00	42·50	40·00	37·50	
41	75·61	73·17	70·73	68·29	65·84	63·41	60·97	58·53	56·09	53·66	51·22	48·78	46·34	43·90	41·46	39·02	
42	76·19	73·81	71·43	69·06	66·67	64·29	61·91	59·53	57·17	54·76	52·38	50·00	47·62	45·24	42·86	40·48	
43	76·74	74·42	72·09	69·76	67·44	65·12	62·79	60·46	58·14	55·81	53·48	51·16	48·84	46·51	44·19	41·86	
44	77·35	75·08	73·80	71·53	69·25	66·98	64·70	62·43	60·15	57·88	55·60	53·33	51·05	48·78	46·50	44·23	
45	77·78	75·55	73·33	71·11	68·89	66·67	64·44	62·22	60·00	57·89	55·55	53·33	51·11	48·89	46·67	44·44	
46	78·26	76·08	73·92	71·74	69·57	67·39	65·22	63·04	60·94	58·77	56·52	54·35	52·17	50·00	47·83	45·64	
47	78·72	76·59	74·47	72·34	70·21	68·09	65·96	63·83	61·70	59·57	57·44	55·32	53·19	51·06	48·93	46·81	
48	79·17	77·08	75·00	72·92	70·83	68·75	66·67	64·58	62·50	60·42	58·33	56·25	54·17	52·08	50·00	47·92	
49	79·59	77·55	75·56	73·47	71·43	69·32	67·35	65·30	63·26	61·22	59·18	57·15	55·11	53·07	51·02	48·98	
50	80·00	78·00	76·00	74·00	72·00	70·00	68·00	66·00	64·00	62·00	60·00	58·00	56·00	54·00	52·00	50·00	
51	80·39	78·43	76·47	74·51	72·55	70·59	68·62	66·66	64·70	62·75	60·78	58·82	56·86	54·90	52·94	50·98	
52	80·77	78·84	76·92	75·00	73·07	71·15	69·23	67·31	65·38	63·46	61·54	59·61	57·69	55·77	53·85	51·92	
53	81·13	79·26	77·36	75·46	73·58	71·61	69·81	67·92	66·03	64·15	62·25	60·37	58·49	56·60	54·71	52·83	
54	81·49	79·64	77·78	75·93	74·08	72·23	70·38	68·52	66·67	64·82	62·97	61·12	59·26	57·41	55·56	53·71	
55	81·82	80·00	78·18	76·36	74·54	72·72	70·91	69·09	67·27	65·45	63·63	61·81	59·99	58·18	56·36	54·54	
56	82·14	80·36	78·57	76·79	75·00	73·21	71·43	69·64	67·86	66·07	64·29	62·50	60·71	58·93	57·14	55·36	
57	82·45	80·70	78·95	77·19	75·43	73·68	71·93	70·17	68·42	66·66	64·91	63·13	61·38	59·63	57·88	56·13	
58	82·75	81·03	79·30	77·58	75·86	74·13	72·41	70·68	68·96	67·24	65·51	63·79	62·06	60·34	58·62	56·89	
59	83·04	81·35	79·66	77·97	76·27	74·58	72·88	71·18	69·49	67·80	66·10	64·41	62·72	61·02	59·32	57·63	
60	83·33	81·67	80·00	78·33	76·67	75·00	73·33	71·67	70·00	68·33	66·67	65·00	63·33	61·67	60·00	58·33	

CHAPTER XV.

THE CONCENTRATION OF THE SYRUP TO MASSE-CUITE.

The juice after being treated in the multiple effect evaporator leaves as a thick syrup of density about 1.25 and containing about 55% of solids in solution. Before being passed on to the vacuum pans to be boiled to grain, in some factories where high-class consumption sugars are produced a further clarification is made. This may be done either with the object of removing bodies which have been thrown down in the evaporation or with the intent of finally correcting any acidity or alkalinity. In the former case the syrup may in a few instances be filtered through the mechanical filters described in a previous chapter, but it is only in factories working up canes of exceptional purity that the syrup is sufficiently free to allow this, and the removal of the suspended impurities can only, in general, be effected by subsiding. When a second tempering with acid or alkali is made, eliminators, such as have already been described, serve the purpose. The removal of a large portion of the impurities thrown out can to a large extent be effected by filtration through sand filters in the passage of the partly concentrated juice from vessel to vessel of the evaporator.

The vacuum pan is the name given to the vessel in which the final concentration takes place; the means of obtaining and maintaining the vacuum are precisely similar to those given in the preceding chapter, and the principles detailed there are, *mutatis mutandis*, applicable to the single effect pan. Some points of special interest are, however, discussed later. The vacuum pan was invented early in the nineteenth century by Howard, whose name is also associated with the invention of the filter-press. As made by him the apparatus consisted of a double-bottomed shallow iron pan, steam being admitted to the double-bottom; a partial vacuum was obtained by condensing the vapour given off by a jet of water allowed to gravitate down from an overhead tank; no pump was at first employed.

The great majority of vacuum pans in use at the present day consist of a vertical cylindrical iron body of approximately equal length and

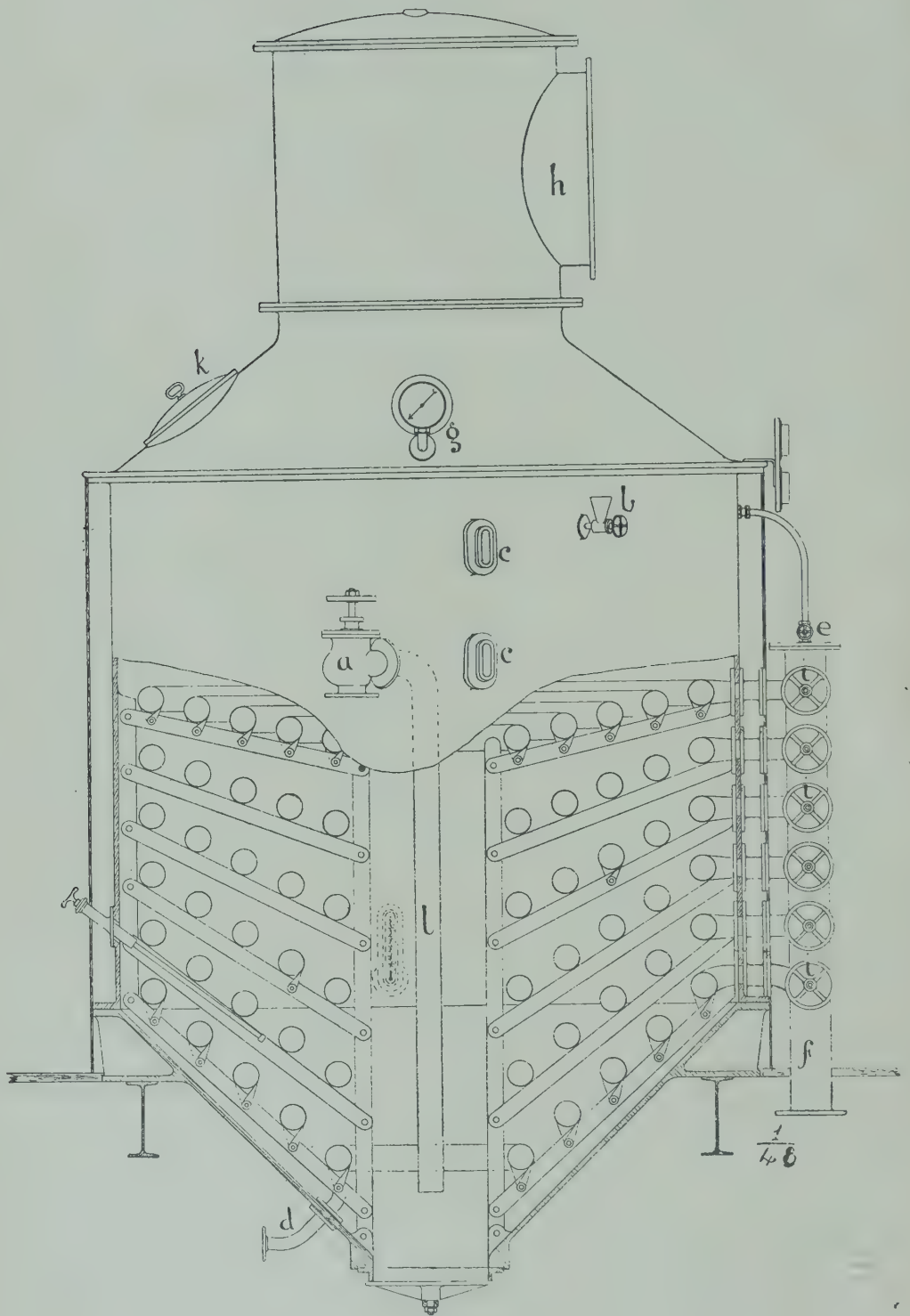


FIG. 80.

width; this is often called the belt and is covered on the top by a spherical or conical cap called the dome; on the dome is placed the head box whence leads the vapour pipe to the pump; the lower portion of the pan is formed by an inverted cone called the saucer or well; the masse-cuite is discharged by a door at the centre of the well. In what may be referred to as the Standard type of vacuum pan, the heating surface consists of a number of helical copper coils, reaching from the bottom to a little above the centre of the pan, and so arranged as to divide the heating surface as uniformly as possible. In *Fig. 80* is shown a view partly in section and partly in elevation of a modern pan. The coils are seven in number and are $4\frac{1}{2}$ inches in diameter; they are supported by stay rods fixed to the side of the pan; they each pass through the side of the pan and communicate with the steam pipe *f*; each coil has its own valve *i* whereby steam can be admitted to any or all of them; connection is also made to a second pipe (not shown) carrying exhaust steam, so that this can be utilised when available. In modern practice the maximum length of coil used is one about 200 times the diameter; beyond this length it is found that the condensed water does not leave the pipe fast enough to obtain an efficient heating surface. The syrup is brought into the pan by the pipe *l* controlled by the valve shown at *u*; this pipe reaches down to the bottom of the pan so that the lighter syrup enters at the bottom and rising upwards becomes uniformly distributed; each coil is closed by a flange *d* at its lowest point, which carries a smaller pipe conveying the water of condensation to a steam trap or separator; at *e* is shown a pipe connected to the main steam whereby steam is introduced to the interior of the pan for the purpose of removing sugar after a strike; at *k* is a manhole giving access to the pan, at *g* the vacuum gauge, at *c* a sight glass, and at *b* the cock for breaking vacuum; in the pan shown there are approximately 1,000 square feet heating surface, the vessel holding when full 30 tons of masse-cuite. Special points with regard to this type of pan are that the coils are often made double, alternately right and left handed helices, and that the condensed water is trapped at every fifty feet or so of coil.

In order to overcome the tendency for condensed water to bank up in long coils, pans of similar design to the above but with lyre-stopped coils are now made. In these pans each coil forms only one convolution, and is a complete unit in itself; as many as eight coils form a nest in one plane, the ends which receive steam passing

through the side of the pan into a collector box, a similar box collecting the other ends of a nest ; such a nest is shown in plan in *Fig. 81.*

Besides pans of the general design described above, considerable numbers of horizontal tube pans are constructed ; these differ in no essential detail from a vessel of a horizontal tube multiple effect shown in *Fig. 63* ; the tubes which form the heating surface are

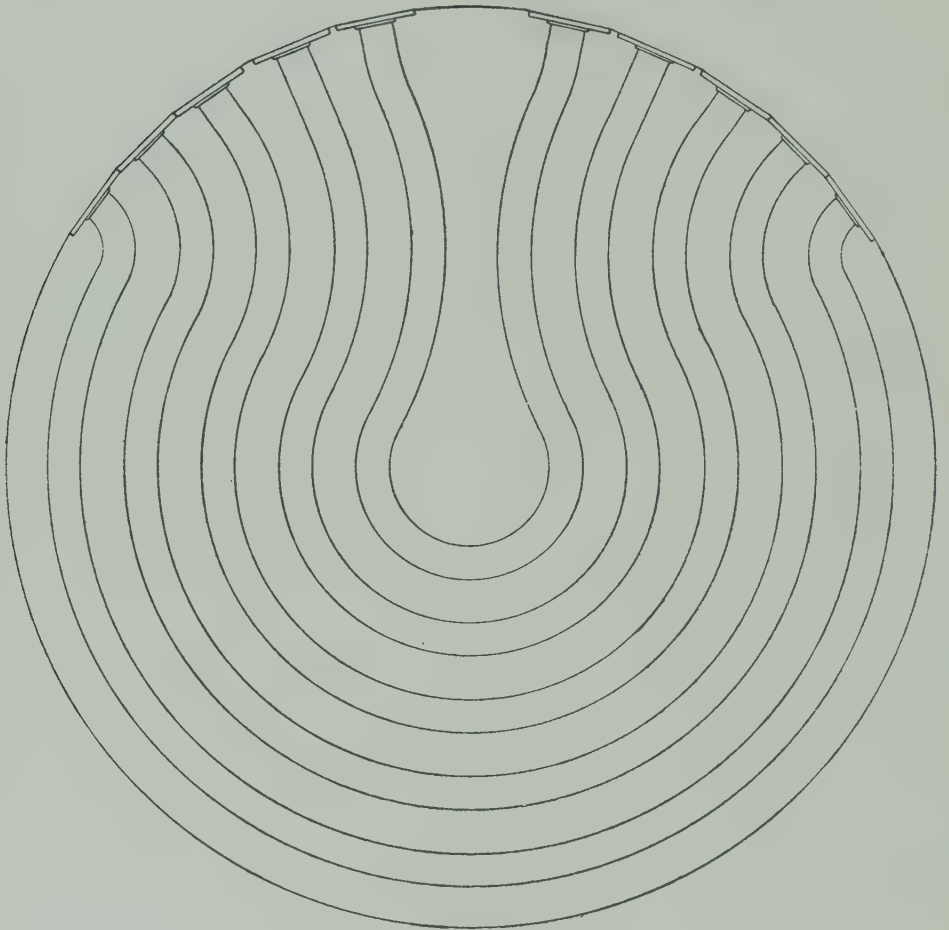


FIG. 81.

divided in the steam chest into sets by horizontal partitions, each compartment having its own steam connection and condensed water outlet ; the discharge valve is placed centrally at the bottom of the pan, and sometimes runs the entire length. Pans of this design have the advantage that the heating surface is easier to construct, and, further, that a leak in one tube only invalidates that particular tube and not the whole set ; these pans are not, however, largely used.

The *Welner-Jelinek* single effect pan follows the same general lines as the multiple evaporator; instead, however, of the sides terminating at right angles to the bottom, they are vertical for a part only and afterwards slope in at an angle of 45° , being about two feet distant from each other at the bottom of the pan. The heating surface consists of horizontal tubes, about one inch in diameter and arranged in nests; each tube is distant from the next by about four inches; the nests are placed above each other in stages of from two to four chambers, varying with the size of the pan, and steam can be admitted independently to each stage.

In a fourth type of pan the general design of the *Standard* is followed, but the heating surface is formed of a calandria, precisely the same as described when dealing with the vertical submerged tube multiple evaporator but with tubes of about four inches in diameter; this type of pan is but little used.

The pan introduced and patented by Dr. Winter, in Java, is one of ordinary design, but has means provided for the admission of air in a very fine state of sub-division from the bottom of the pan upwards; the object of this admission, which is only made at the conclusion of boiling, is to obtain a vigorous and complete agitation of the *masse-cuite*; at the same time, the vacuum being partly destroyed, the temperature rises, and any small fine crystals which may be present are re-dissolved; on cooling in motion the crystals that have just been dissolved separate out on the larger crystals already present.

The discharge of *masse-cuite* from a pan usually takes place by gravitation only; in some systems a helical screw is arranged in the pan to force the *masse-cuite* out, and in others compressed air is used; a quick discharge adds very considerably to the capacity of the boiling plant; it is not at all unusual to see a pan take an hour or more to discharge a strike of close boiled *masse-cuite*.

The chief points in connection with the design of a pan are:—

1. The coils should not be too close together, else free movement of the *masse-cuite* is prevented.
2. The heating surface should be uniformly distributed through the body of the pan.
3. The coils should not be too long, else the condensed water within the coil banks up and makes a portion of the coil useless. Practical experience has shown that the efficiency of a coil decreases very rapidly when the length exceeds 200 diameters.

4. The discharge valve should be as large as possible, within reasonable limits, and the sides of the saucer should be deep; two feet diameter is about the practical limit of the size of the discharge, and the sides of the saucer should slope at an angle of about 45° .

In general, in modern factories, and always unless the engines are large steam consumers, all the exhaust steam is used up by the juice heater and multiple effect apparatus, and none remains for the pans; the majority of sugar manufacturers object with considerable reason to the use of high pressure steam in the pans, and consequently the main steam is reduced before entering the coils to a pressure generally lying between the limits of 10 lbs. and 20 lbs. per square inch; the objection to the use of high pressure steam is the tendency towards local overheating and caramelisation of the sugar. This danger is not so great if the circulation is kept very rapid, and the use of high pressure steam adds very considerably to the capacity of a pan, the passage of heat being proportional to the difference in temperature between the exterior and interior of the coils; pans are now constructed, especially by American firms, to work with steam pressure of 50 lbs. per square inch, or even more.

The calculation of the heating surface for a pan can be made on lines similar to those detailed when dealing with the multiple effect; the mean temperature of the boiling mass is considerably higher than the temperature corresponding to that shown on the pressure gauge, but, whereas in the evaporator the column of juice is of constant height, in the pan the height of the boiling column of syrup is constantly increasing, so that the efficiency of the heating surface is constantly decreasing; this is the more marked the higher the pan is, and consequently in larger pans the efficiency of the heating surface tends to become less than in smaller pans. As an example of an actual case let the maximum height of the *masse-cuite* in a pan be ten feet, so that the average height for the boiling is five feet; the average density of the contents of the pan can only be very approximately estimated; the syrup enters at a density of, say, 1.25, and is discharged as *masse-cuite* at a density of about 1.50; allowing for the decrease in density due to emulsifying with gases, as was done when dealing with the multiple evaporator, the mean density of the boiling mass is found to be about 1.21; the weight of a column of liquid five feet high and of density 1.21, and of one-inch cross section, is equivalent to a column of mercury 5.34 inches high, or to a pressure of 2.62 lbs. per square inch; if the pressure of the liberated vapour

be taken as 2.42 lbs. per square inch corresponding to a vacuum of 25 inches, the mean pressure of the vapour at the moment of its formation is $2.62 + 2.42 = 5.04$ lbs. per square inch, corresponding to a temperature of 162° F., which may be taken as the mean temperature of the boiling mass.

Now the mean pressure of the steam in the coils may be taken as 20 lbs. per square inch, corresponding to a temperature of 259° F. The difference in temperature between the heating steam and the boiling liquid is then 97° F.; for a triple effect dealt with in the previous chapter a mean temperature difference of 24.3° F. was obtained. A modern triple effect evaporator will evaporate 6 lbs. of water per square foot per hour, so that on these grounds a single effect pan should evaporate under the conditions detailed about 24 lbs. As a matter of fact, experience has shown that in the single effect vacuum pan an evaporation of only 12 to 15 lbs. can be reckoned on; the greater density of the material under treatment implying greater viscosity—and consequent greater difficulty—for the disentanglement of vapour, and at the same time decreasing the coefficient of transmission of heat. In addition, whatever be the actual evaporation during working for a part of the operation, the whole heating surface is not in use. As a rule, modern pans have a capacity of about 70 lbs. of *masse-cuite* per square foot of heating surface; these data are sufficient to calculate the size of pans for the concentration of any given quantity of syrup.

The effect of a low vacuum in the single effect pan is not so noticeable as affecting the temperature difference as in the multiple effect; if in the example worked above, a 27 inch vacuum be assumed, the mean pressure of the vapour at the moment of its formation is found to be 3.86 lbs. per square inch; corresponding to a temperature of 152° F., giving a temperature difference of 107° F. as compared with 97° F. or roughly 10%; for the triple effect considered in the previous chapter the same final vacua altered the temperature difference to the extent of 30%.

The actual process of boiling the pan may be divided into three stages: the granulation, the growing of the crystals, and the bringing up to strike. The granulation is effected by forming in the pan a solution of sugar saturated at a certain temperature, and then by causing the temperature to fall to make the sugar crystallise. Different methods for effecting this exist: the temperature may be lowered by increasing the quantity of injection water and so obtaining

a more complete vacuum, by shutting off the supply of steam from the coils, or by introducing a quantity of cold syrup; in whatever way the granulation is obtained the sugar separates as minute, barely visible crystals. In forming grain some pan boilers take in at one charge the whole amount of syrup from which they intend to granulate, and others take in smaller charges gradually working up to the requisite amount. Instead of forming grain from the syrup the practice of *seed grain* is extensively followed; in this process a quantity of a small grained sugar obtained from previous work is taken into the pan, together with the first charge of syrup, and the crystals thus introduced form the points upon which the sugar deposits in the subsequent process; the sugar used is generally the small grained sugar resulting from the after-boilings of molasses. One ton of such sugar can in general be used as grain for every 25 or 30 tons of *masse-cuite* that the pan holds. This procedure, besides saving time in boiling the first charge of grain, forms a very economical method of suppressing a portion of the low products. In forming grain the quantity of syrup used for granulation depends on the type of sugar required; when a large crystal is desired only a small quantity of syrup is granulated. This process is known as "graining low down." Forming grain from a large quantity of syrup, known as "graining high up," will result in a sugar with small crystals. After the granulation has been effected, the next step is to feed the grain with charges of syrup, the object of the operator being to deposit the sugar that now separates on the crystals already formed and not to allow it to form new crystals ("false grain or dust"). To avoid the occurrence of a second crop of crystals the pan must be boiled evenly, there must be no sudden alteration in temperature due to variation in quantity of steam or injection water, or by taking in too large charges of cold syrup which, by locally reducing the temperature in a part of the pan, causes a deposit of a fresh crop of crystals. The scheme of feeding the pan continuously instead of intermittently is dangerous, as, owing to alterations in steam pressure over which the pan boiler has no control, slight variations may result in false grain being formed. Should this occur from any cause pan boilers have two methods for its removal: one is to partly cut off the injection water and so raise the temperature within the pan, the finer crystals dissolving; the second method is to take in a large charge of syrup or even juice which dissolves the finer crystals; this method is termed by pan boilers "washing." When

making large grained sugars for direct consumption skilful pan boilers frequently, during the boiling of the strike, take in large charges of syrup for the purpose of dissolving the smaller crystals; this process is called "opening out" or "boiling free," and in skilful hands gives large, fine, bold crystals, but with less skilled operators is liable to cause a serious deposit of false grain. Winter's patent, already referred to, gives another means of removing the smaller crystals.

When the pan is full no more syrup is taken in, but the temperature is gradually raised by cutting off the injection water until the striking point, which can only be determined by experience, is reached; the water content to which a strike can be boiled depends largely on the purity of the juice, but it is also controlled by such influences as the size of the pan outlet, and time available for striking the pan. The greater the purity the less may be the water content, although an impure *masse-cuite* with more water than a pure one may still have a greater degree Balling. After a pan has been once filled it is often advisable to strike out only half, and to continue boiling on the remainder; this process is known as "doubling," and the discharged *masse-cuite* as the "first cut"; the object of this process is to save time and to obtain a large grained sugar in the second and subsequent cuts. This process may, with exceptionally pure juices, be continued four or five times, whilst juices of low purity may not give a single double; in any case, there is always a point beyond which the sugar crystal refuses to grow, and any attempt to further increase its size ends in a fresh deposit of minute crystals.

When the juice is of average purity, the molasses resulting from the curing of the sugar are often taken into the pan and boiled along with the syrup, the object being to obtain as much of the output as possible in first product; this point is more fully discussed in a subsequent chapter.

CHAPTER XVI.

THE SEPARATION OF THE CRYSTALS FROM THE MASSE-CUITE.

The finally concentrated product of the juice, called *masse-cuite*, consists of a magma of crystals of sugar mixed with a thick viscid solution of sugar and of the bodies other than sugar present in the juice; these crystals are separated from the molasses by means of machines known as centrifugals or turbines.

Before describing these machines, the methods of transporting the *masse-cuite* may be shortly detailed. The earliest method and one still often employed is to allow the contents of the pan to discharge into tanks, constructed of wood or iron, which are placed on the basement; the *masse-cuite* is conveyed to these tanks by means of gutters; after remaining in these latter for a day or more the now hard mass is dug out and shovelled into small trucks, the contents dumped into a pit and elevated to a receiver by means of a chain pump; in this receiver revolves a horizontal shaft on which are fixed teeth perpendicular to its axis along a helical curve; these teeth in turning pass between the bars of a grill and thoroughly mix the *masse-cuite*. The apparatus is known as a pug mill, sugar mixer or *malaxeur*. From this receiver the *masse-cuite* (which in case it is too stiff has been mixed with molasses from a previous curing) is discharged into small suspended trucks running along an overhead railway; the trucks each hold sufficient for one charge of a turbine; this is perhaps the oldest method of conveying *masse-cuite* and the one which requires most hand labour. The overhead railway can easily be dispensed with by placing the *malaxeur* directly over the centrifugals and allowing it to discharge direct; and the chain pump, by receiving the *masse-cuite* in trucks running on rails and digging directly from the trucks into the pug mill. Nearly all hand labour may be eliminated by arranging the pans on a high level so that they may discharge into waggons or receivers which are themselves at a higher level than the turbines; in this case the *masse-cuite* gravitates the whole way down to the turbines.

Another method which is extensively used is to receive the masse-cuite in small cans holding each about 500 lbs. of masse-cuite ; after cooling, these cans, which can easily be wheeled about, are elevated by a hydraulic lift, turned over and their contents discharged into the pug mill by means of compressed air ; this method forms a very convenient, cheap and clean process for conveyance of masse-cuite. The method of conveying by compressed air is referred to in the next chapter.

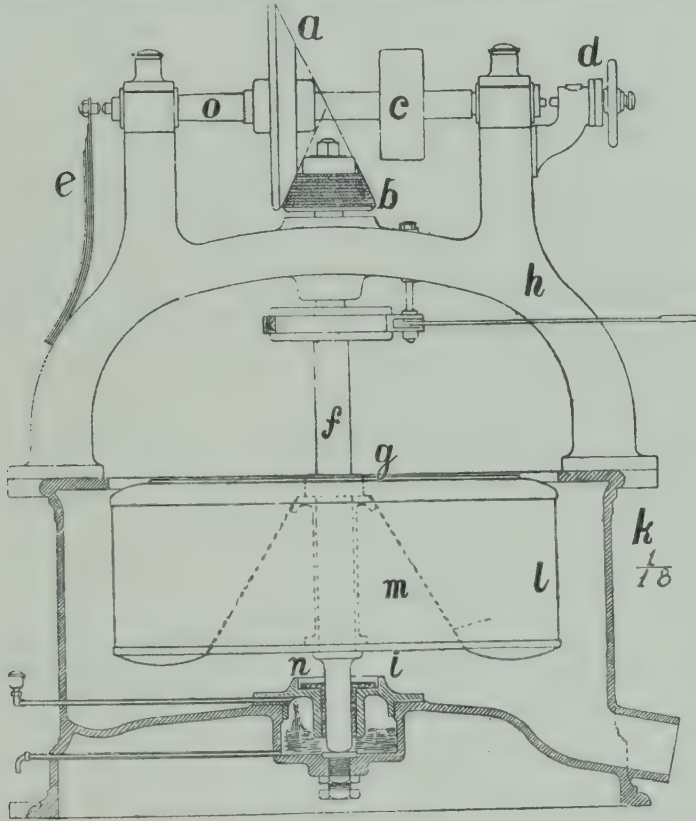


FIG. 82.

The cured and dried sugar is in modern machines discharged into a conveyor underneath the turbines ; this conveyor usually takes the form of a trough in which rotates a helical screw, which carries the sugar forward to a small pit, whence it is elevated to the store by an endless belt to which are attached small scoops or buckets ; to avoid crushing the sugar it is often conveyed by a "*grasshopper*" carrier ; this is a trough fixed at one end only and under the other end revolves an eccentric wheel, the sugar being jerked forward by the motion of the eccentric. In older styles of machines the sugar is lifted out of the machine by hand and carried by manual labour to the store.

The earliest employed method of separation of sugar from molasses was by drainage, the masse-cuite being packed into hogsheads with

perforated bottoms through which the molasses drained; in certain districts this process still obtains but the use of centrifugals or turbines is practically universal.

A centrifugal consists essentially of a vertical cylindrical perforated basket, which is caused to revolve at a high speed; within the perforated basket is fixed a wire gauze strainer containing from 400 to 500 perforations per square inch, the revolution of the basket causing the magma of crystals and molasses to be violently thrown against the inner wall; the molasses and a portion of the crystals pass through

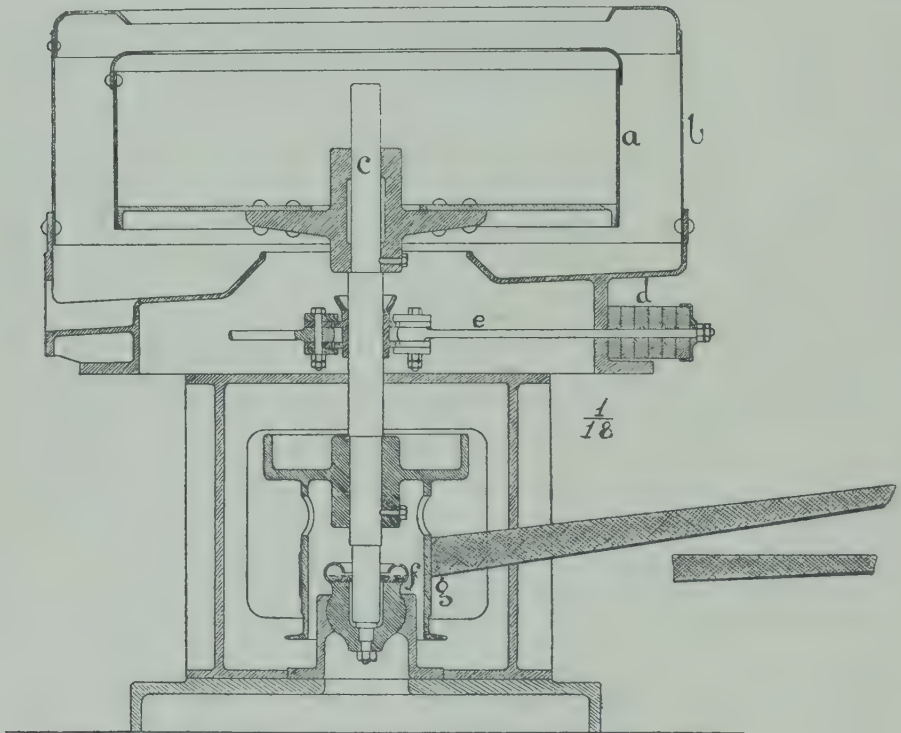


FIG. 83.

the gauze, which retains the greater portion of the crystals. Without the perforated inner basket is a casing which forms a chamber for the reception of the molasses, whence they are conducted by a spout to a gutter.

In the earlier forms of centrifugals the spindle carrying the basket revolved in fixed bearings. *Fig. 82* shows a view of this type of machine; *f* is the spindle revolving in two brasses, *i* and *j*, the lower brass *i* being fixed in the bottom of the monitor outer casing *k* and the upper one *j* in the cross-piece of the frame *h*, which is supported on and bolted to the outer case; the basket *l* is secured to the spindle by the nut *g*, screwed down on the cone *m*, which rests on the bottom of the basket; a collar *n* on the spindle prevents any downward

movement. Motion is transmitted to the machine by a belt drive on the pulley *c*, and by the friction cones *a* and *b*; the driving cone *a* is of steel, and the driven cone *b* of mill board; the driving spindle *o* is carried on two bearings, the cones being kept in contact by the pressure of the spring *e* on one end of the spindle; the cones are thrown out of gear by means of the screwed piece *d* moving the spindle outwards against the pressure of the spring.

In *Fig. 83* is shown a type of a pivot under-driven machine, which equally with the above is common on the continent and wherever the influence of continental engineers is felt. The basket *a* is fixed to the spindle *c*, which is supported by the footstep bearing *f*, and the collar formed by the iron bars *e*; these bars are screwed up against pieces of indiarubber *d*, whereby the shock of the machine is partly absorbed; the machine is driven by belt drive on the pulley *g*.

All centrifugals of the two types already described use a large portion of the power supplied in keeping the revolving basket in fixed bearings. The centrifugals in most common use are of the suspended type, in which the basket is free to move within certain limits, and to find its own centre of gravitation. In *Fig. 84** is shown a section of the *Weston* type of centrifugal machine as arranged for belt drive. SB is the suspending block firmly bolted to an overhead beam or framing CF; EB are elastic buffers resting on the block SB, and above this is suspended from the elastic buffers the spindle IS by means of a top nut and washer; this spindle oscillates with the machine, but does not revolve; at BB is shown the bottom revolving bearing; at OS is shown the outer revolving spindle attached to the driving pulley DP. The perforated basket is shown at B, and the outer casing at OC; and sugar is discharged through a circular aperture at the bottom of the basket, kept closed when necessary by the valve DV, which slides up and down the outer spindle; the bottom part of the outer spindle forms an oil bath. The elastic buffers are an essential feature of this type of centrifugal. The *masse-cuite* will from time to time assume different centres of gravity: instead of attempting to restrain the machine in a fixed position this system allows a certain freedom of movement.

The *Hepworth* suspended centrifugal differs from the above in that the whole machine is suspended; referring to *Fig. 85*, it will be seen that *a* is the ball of a ball and socket joint formed in the bracket *m*, from which pass three or four rods *k* which support the outer casing

* From a drawing supplied by Messrs. Pott, Cassels and Williamson.

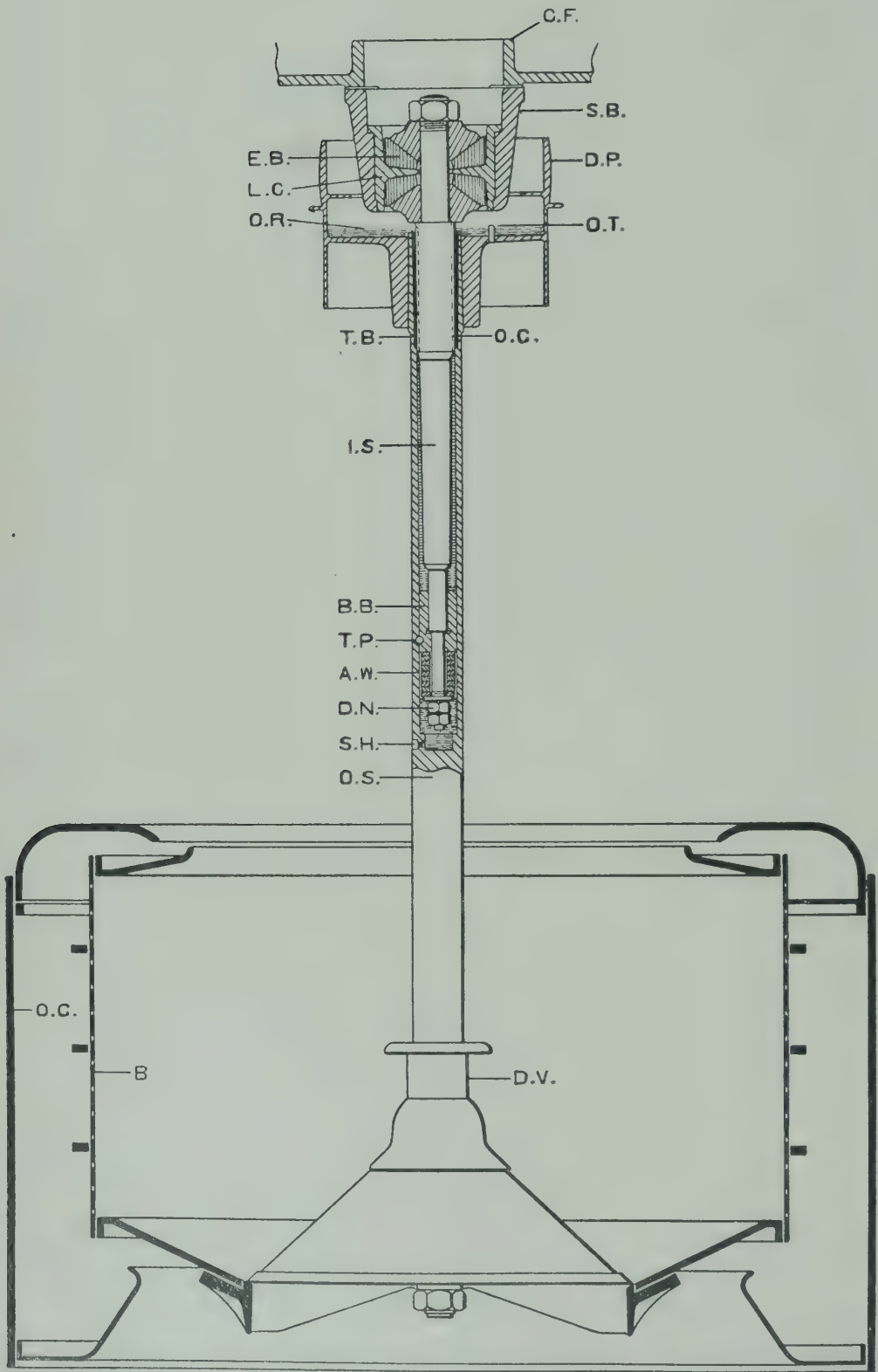


FIG. 84.

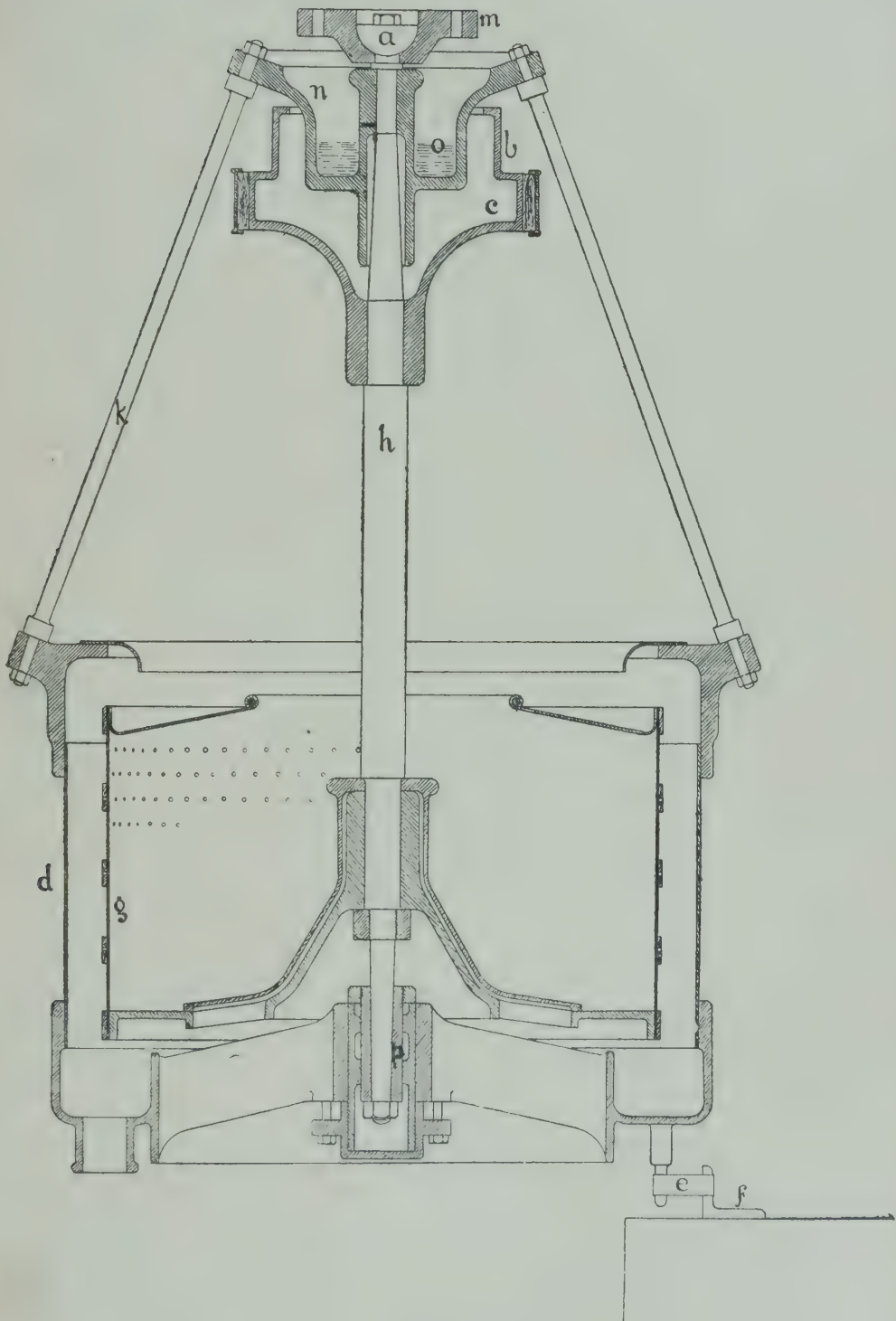


FIG. 85.

d of the machine; the bracket *n* is so formed as to make a reservoir of oil; the spindle carrying the revolving basket *g* is shown at *h*; this spindle works in two bearings seen at *o* and *p*; the brake is seen at *c*, and the brake band at *l*; cast on the bottom of the outer casing are lugs on which are placed indiarubber bands *e* passing over the fixed brackets *f*; these indiarubber bands are for the purpose of controlling the movements of the machine, and at the same time allowing a certain freedom of movement.

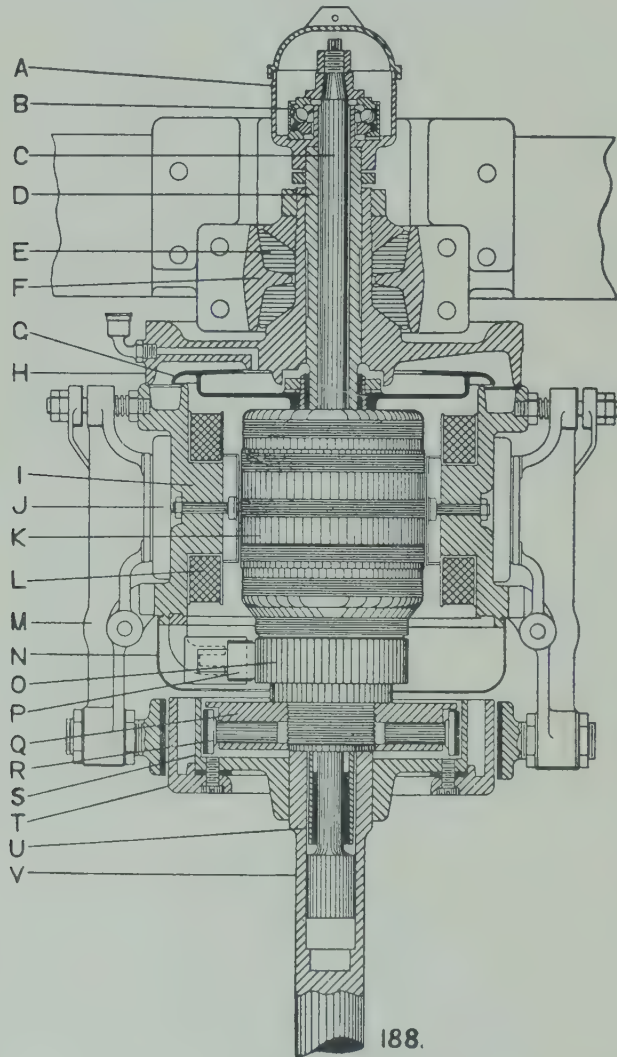
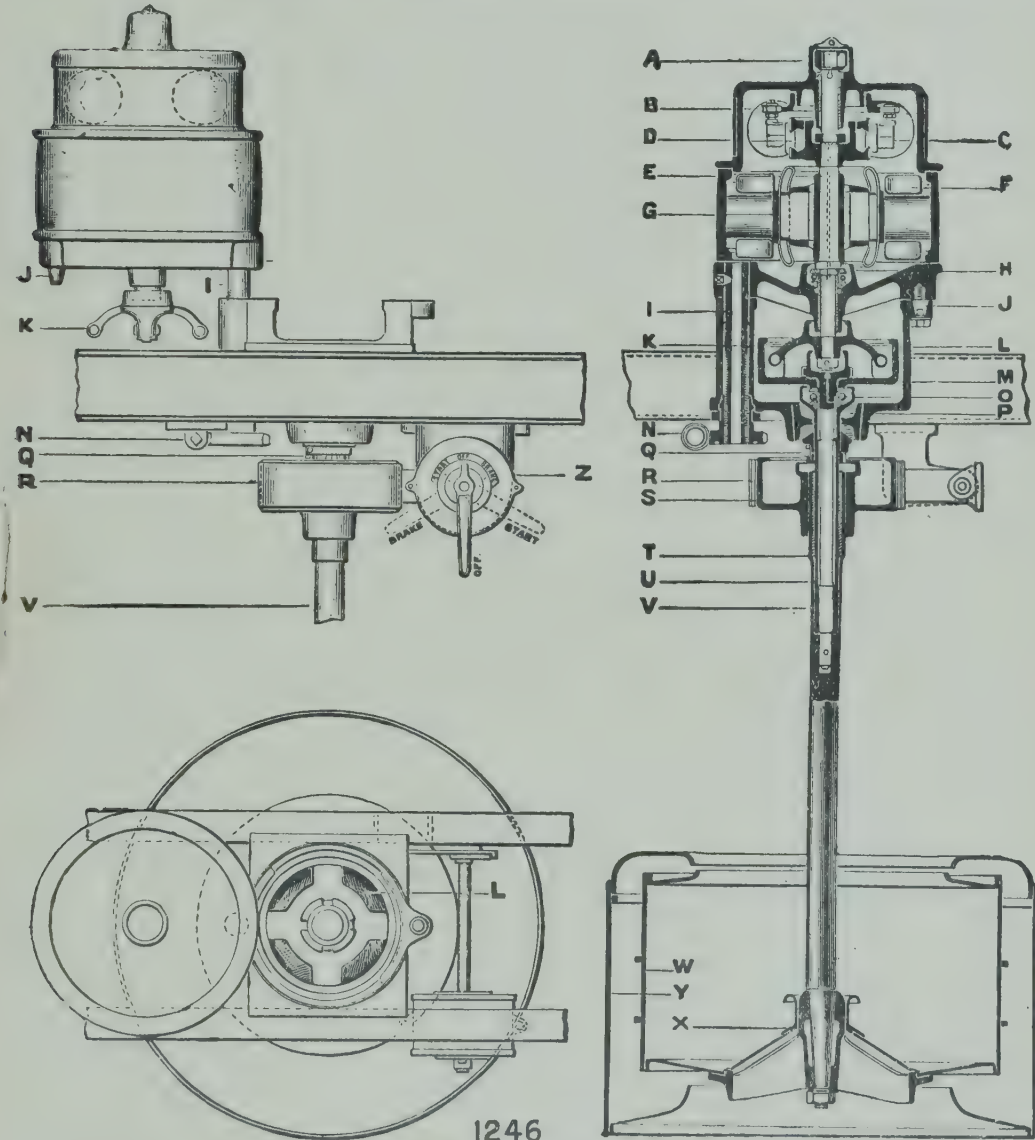


FIG. 86.

For many years the standard size of basket adopted has been one of thirty inches diameter; such a machine is run at a speed of 1,200 to 1,500 revolutions per minute. Latterly larger machines, up to forty-eight inches diameter, have been erected in many instances; the larger sized machine economises labour, but in proportion to sugar cured takes very considerably more power to drive.

At the present moment the great majority of centrifugals are belt driven, the whole power for driving pug mill, elevators and machines, being derived from one engine ; the ratio of gearing between machine and engine is usually of the order 20 : 1 ; the engine is geared to an intermediate shaft in the ratio of about 1 : 3 ; this shaft is in turn geared



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FIG. 87.

to the counter-shaft of the centrifugals, the ratio of gearing between counter-shaft and centrifugal being of the order 1 : 6 ; the engine supplying power makes from fifty to sixty revolutions per minute. The proportions are general for thirty-inch machines ; with machines of larger diameter a lower number of revolutions per minute will give the peripheral speed required to force out the molasses. Since so

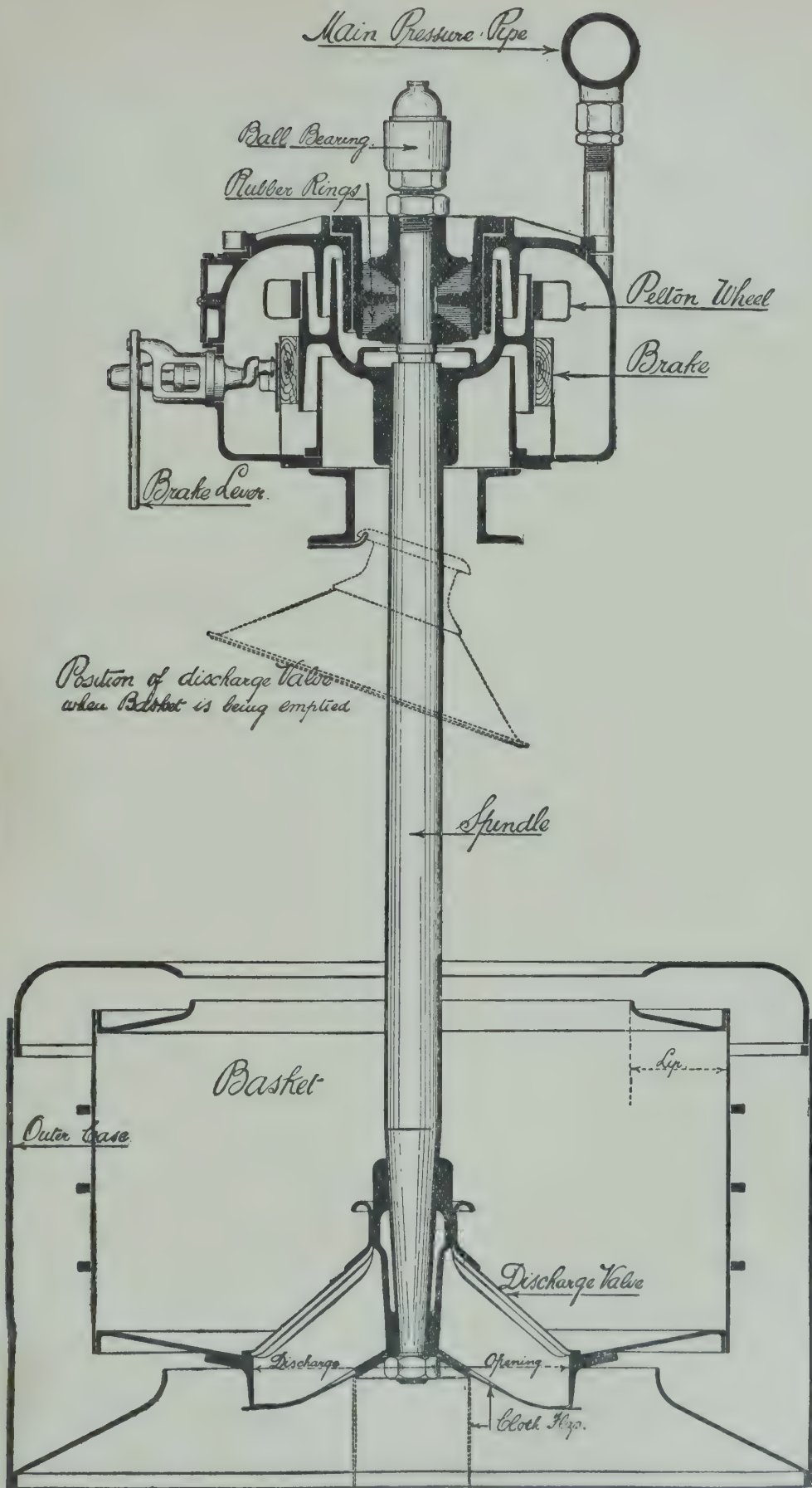
high a ratio of gearing occurs with belt-driven machines, it is apparent that any variation in speed of the engine is multiplied in the centrifugal, and the engine must be supplied with a delicate and sensitive governor; a system of belt-driven machines, too, does not afford a means of varying the speed of any one machine independently of the rest, or of getting up speed slowly, as is important in curing low grade sugars. In view of these objections to a geared-up belt-drive, batteries of machines, independent of each other, have been developed; the system used is either an electric or water-drive. In *Fig. 86* is shown a view of the electric-driven spindle as made by Messrs. Pott, Cassels and Williamson. The lettering is as under:— C inside spindle, D intermediate spindle, H top plate of motor case, K armature, L magnet coils, M brake, O commutators, P brushes, Q driving disc, R friction arms, S pulley, T brake pulley. On switching on the current the magnet coils pull off the brake and the armature being loose on the outer spindle immediately revolves at a high speed and gradually communicates motion to the spindle V by means of the friction arms which are pressed out against the pulley.

In *Fig. 87* is shown a view of the electric-driven spindle as made by Messrs. Watson, Laidlaw & Co. The lettering is as follows:— C brushes, D commutator, E motor spindle, F field coils, G armature, L friction shoes, N worm and wheel, R brake, T inner revolving spindle, U stationary sleeve, V outer revolving spindle, Z switch. An installation of machines of this type, though more expensive than one of the older belt-driven type, will in all probability cost less in upkeep, and the advantages of the independent drive are self-evident.

In *Fig. 88* is given a view of the water-driven machine of Messrs. Watson, Laidlaw and Co.. This type of machine has in recent years been very extensively adopted. The head of water necessary to drive the machines is obtained from a double acting pump; no large supply is needed, as after discharge from the Pelton wheel fitted on the outer spindle, the water flows back to the supply tank of the pump. Two jets are supplied, and after full speed has been obtained, one is automatically cut off; if it is desired to get up speed slowly one jet only is used, an advantage in curing low-grade products.

In *Fig. 89* is shown a section of the Moody-Stuart ball-bearing attachment as made by Messrs. Pott, Cassels & Williamson. B B is the ball bearing arranged in the oil bath O B; the rest of the lettering is as in *Fig. 84*.

The capacity or output of machines depends very largely on the



2488.

FIG. 88.

condition of the masse-cuite. With average first masse-cuite a 30 in. machine, curing refining crystals, will turn out from 1,600 to 2,000 lbs. of sugar per hour; the older types with fixed spindles, in which time is wasted in lifting sugar over the tip of the basket, can only be depended on to cure little more than half this quantity. The output of molasses sugars per machine is in general only one quarter of

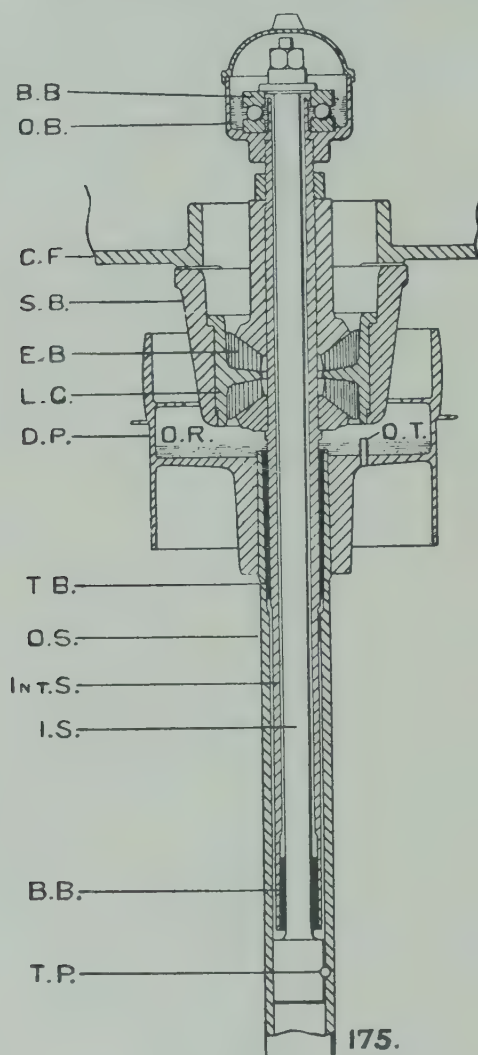


FIG. 89.

what it is when turbinizing first products; the baskets having to run longer with each charge and the recovery of sugar being rather less than half what is the case with first masse-cuites.

When making high-grade white crystals the sugar is purged with high-pressure steam after washing with water. This process, of course, diminishes the output of sugar and quantity of masse-cuite cured. A 30 in. modern suspended machine will cure in one hour

about half a ton of masse-cuite, only half this quantity being the average output of a machine with fixed bearings. When using steam in the centrifugals, it is commonly introduced by a pipe which is carried over the monitor case and continued downwards inside the basket, the pipe being perforated on the side nearest the wall of the basket. Another arrangement introduces the steam through the spindle on which the basket is hung, the spindle being perforated for this purpose. Whichever method is adopted it is of essential importance that the steam be dry, else avoidable losses due to the presence of hot water are incurred; to this end the pipe carrying the steam should be carefully lagged and, better still, a separator should be interposed between steam-pipe and machine. The recovery of white crystals varies, of course, with the care and skill used in boiling the masse-cuite: as a general rule from 10% to 15% less sugar, recoverable in after products, is obtained than when curing dark or yellow crystals without steam.

The various questions that arise with regard to the treatment of masse-cuite in the centrifugal have been carefully studied by Geerligs (*Sugar Cane No. 309*). He determined first from actual factory experiments the yield in the same masse-cuite when boiled to different degrees of concentration and found that although more sugar separates out in close boiled than in more open boiled masse-cuite, the yield in crystals is not augmented as more water is required to remove the more viscid molasses; on the other hand there is a limit to the amount of water which should be left; he found the best results were obtained when the true water content was 8% to 9%, corresponding to an apparent water content of 5% to 7%.

He found, too, that when impure masse-cuites were cured hot, direct from the pan, that practically the same amount of crystals were obtained as when cured cold, but that with pure masse-cuites considerably more crystals were obtained when cured cold. This result is of course due to the sugar in the impure masse-cuite, when cooling, separating as small grain; in the pure masse-cuite of less viscosity to the sugar on grain already present.

As a general rule the amount of sugar present as crystals is very much the same in all first masse-cuites of both high and low polarisation, and it is the form and shape of the crystals that control the yield in the centrifugal; this point is of such interest that the following table due to Geerligs is reproduced here where it will be plainly seen on inspection that the purer masse-cuites gave a larger yield,

not because more sugar was present as crystals, but because a larger proportion of the crystals were recovered.

Polarisation.	Glucose.	Water.	Quotient of Purity.	Crystallised Sugar.	Sugar in the Syrup.	Crystals obtained.	Crystals lost.	Sugar obtained
	%	%						
74.1	11.07	9.02	78.06	61.62	12.48	51.1	10.11	54.8
78.9	8.99	7.76	83.58	68.22	10.68	58.81	9.41	64.3
79.0	8.47	7.82	83.72	69.09	9.91	55.28	13.81	58.8
81.1	6.93	9.66	87.23	66.96	14.14	60.0	6.96	62.85
84.1	4.81	8.11	88.62	67.81	16.29	64.1	3.71	66.1
84.2	3.20	9.77	90.28	64.13	20.07	62.01	2.12	67.5
84.8	2.74	8.23	88.93	62.93	21.87	59.46	3.47	63.40
86.7	1.83	7.58	93.45	67.10	19.60	66.80	0.30	74.1

That the size of the crystals has much to do with the removal of molasses is self evident, when it is remembered that the larger the grain the less is the area of contact for the molasses, and consequently the latter are the more easily removed; Geerligs demonstrated this by allowing syrup to drain from artificial masse-cuite, in which the size of the grain varied; his results are given below:—

Diameter of the grain	m.m.	Syrup run off;	
		grams.	
.. ..	3.0	..	300
.. ..	2.0	..	265
.. ..	1.5	..	200
.. ..	1.0	..	115
.. ..	0.5	..	20

Mixtures of 600 grams sugar crystals and 400 grams of syrup, as indicated above, were allowed to drain for three days, the larger the diameter of the crystals the greater the quantity of syrup run off.

The general rules for the treatment of masse-cuites may then be summarised. Impure masse-cuites with purity under, say, 80-81, give best results when not boiled too close and when cured hot; purer masse-cuites may be boiled to a less water content and should be cured cold; as large and even a grain as possible should be made. This is a point where the skill of the pan boiler is shown, and is really of very great importance; a juice which, in the hands of one pan boiler, gives a masse-cuite from which 56% to 58% of crystals are recovered may, when boiled by one more skilful, give a recovery of 60% to 62%.

CHAPTER XVII.

THE CRYSTALLISATION IN MOTION PROCESS.

This process, which was originally conceived many years ago and abandoned owing to its principles not being thoroughly understood, has of late years been widely adopted in both raw and refined sugar factories. Information respecting its application to the cane sugar industry depends very largely on the researches of Geerligs. This investigator has shown that the amount of sugar separating out as crystals in first masse-cuites is always very nearly the same, an average figure being 65% (*see Table in previous chapter*). When working with juices of high purity, say 85 and over, nearly all these crystals are present in a form that can be readily recovered in the turbines, but with impure masse-cuites resulting from juices of low purity and especially such as contain a large proportion of glucose, the mother liquid becomes extremely viscous and the recovery on curing does not nearly approximate to the amount of sugar crystals present; the reason for this is that a supersaturated solution of sugar is formed in the pan; on cooling at rest eventually all the sugar that can crystallise does so, but in the case of a viscid impure mother liquor the sugar deposited on cooling forms new small crystals whilst in a purer less viscid masse-cuite it is deposited on crystals that are already formed; in the former case the latest formed small crystals pass through the turbines and are lost as first product.

The simplest application of crystallisation in motion follows directly on the foregoing facts; the masse-cuite, as it leaves the pan, is received in vessels provided with a stirrer, kept continually in motion at the rate of from one to one and a half turns per minute; the effect of this is that the sugar crystallising on cooling has opportunity to deposit on grain already formed. This system gives the best comparative results with impure juices, as it is with these that a notable quantity of fine grain is formed on cooling; with purer juices, the benefit is not so pronounced.

The plant required for this process is of the simplest construction. A crystalliser consists of a cylindrical vessel with a shaft carrying

paddles passing along the longitudinal axis ; motion is usually given to the shaft by a worm or wheel-gear. The vessels are either plain or water-jacketed : the latter is preferable as it allows the cooling to be under more complete control ; the time taken in cooling is usually about 15-16 hours ; the stirrer makes about half a revolution per minute, and, of course, the rapidity of the stirring has its effect on the rate of cooling, and such a rate is to be aimed at as will allow the sugar on cooling to deposit on the crystals already formed without forming any new fine grain. Perhaps the best way of controlling the cooling is that due to Ragot and Tournour : in this design the stirrer consists of a helical coil through which water circulates. It is claimed for this apparatus that first products can be cooled to 100°F. in from six to eight hours, and low products in from 24-30 hours ; the capacity of a mixer is probably trebled by the use of this device. A second method of applying crystallisation in motion is only to cool the after products in motion. In this scheme the first masse-cuite is cooled at rest in wagons or tanks in the usual way and the resulting molasses after boiling are received in crystallisers and kept in motion for from 48 to 72 hours when they are ready to cure. With the customary process of allowing low grade masse-cuites to cool at rest in larger tanks, three weeks is not an unusual time before they are ready to be turbinéd, and this process is economical in labour and in saving the expenses of the after campaign, but from published figures dealing with the process in best sugar houses no greater recovery is to be looked for. This method of working is especially to be recommended for such factories as specialise in high-grade consumption sugars, crystallisation in movement having a tendency to spoil the appearance upon which the value of these sugars depend.

The systematic return of molasses to first masse-cuites, a method of working summarised under the name of "*First Sugar and Molasses*," is intimately connected with crystallisation in motion and forms the most important application of the system. From what has been said above it is at once apparent that factory molasses consist of a nearly saturated solution of sugar and non-sugar, holding in suspension a very considerable quantity of fine grain ; now in the ordinary process of working, the molasses are diluted with water and heated before they are taken into the pan and boiled down to masse-cuite of very little less water content than the original molasses. Now in this process, with perhaps a small limitation referred to below, no more

sugar deposits as crystals than was originally present; it is only the size of the crystals that are changed; instead of there being a very large number of very minute crystals, there is present a smaller number of larger crystals capable of recovery in the turbines; it is the object of the "*First Sugar and Molasses*" processes to recover all this second crop of crystals as a part of the first crop. The method of working is as follows: The pan is boiled in the usual way until about three-fifths full; then hot undiluted molasses from a previous curing, saturated at the ordinary temperature and when cold containing the fine grain mentioned above, are drawn into the pan; the quantity of molasses drawn in is calculated to reduce the purity of the whole strike to about 70. When the pan is full, its contents are struck out into crystallisers and on cooling in motion the fine grain dissolved by the hot molasses deposits on the crystals already formed. By systematically working on these lines first sugar and refuse molasses result. In many installations the addition of the molasses is not made in the pan but in the crystallisers; the principle involved in either scheme is the same. In actual practice it is customary to determine for each purity of syrup and purity of molasses which are to be returned the proportions of each, to reduce the purity of a strike to a fixed figure, generally 70, at which point is obtained as complete a desaccharification of the molasses as is possible. Considerable confusion has arisen about this process, it having been vaguely supposed that in some way cooling in motion caused more sugar to separate than cooling at rest. This is not so; it is only the form of the crystals that is affected, the action being purely a mechanical one. In the same way the addition of molasses to a first *masse-cuite* has been misunderstood, it being supposed that the addition tended to desaccharify the molasses. Now if we have a saturated solution of any matter in contact with the separated solid and add a further quantity of saturated mother liquor, no change can take place in the equilibrium of the system, and this is precisely what happens in the addition of molasses to a first *masse-cuite*.

The term, "supersaturated solution of sugar," used by many writers and recurring frequently in patent specifications dealing with this process, requires explanation. Strictly speaking, no such state as a supersaturated solution exists, the solubility of sugar or any other body in any medium being an absolute constant for a given temperature; now, however, the concentrated solution from which sugar is crystallised is extremely viscid, so much so that it is possible either

by rapid evaporation or by rapid cooling to remove water or lower the solubility with greater velocity than the sugar molecules are able to separate out as crystals; in this way, for periods more or less long, a system of false equilibrium may be maintained in molasses, but eventually all the sugar capable of separating will do so. (As an analogous instance of supersaturation, a glass of champagne slowly giving off bubbles of gas may be quoted: if the wine be disturbed in any way by shock, or even by touching the surface, an instant and violent effervescence occurs; but whether the wine be shaken or left entirely at rest the final condition is the same.) When such a state occurs, the sugar held in supersaturated solution crystallises in the form of small crystals, which, when they occur in the vacuum pan, are called "*false grain*." The object equally of pan boiling and crystallisation in movement, then, is to so control the process that supersaturated solutions do not occur; this is effected by slow evaporation and slow cooling.

A numerical example will make clear the points discussed above.

A first masse-cuite of less than average purity is found on analysis to contain 80.0% of sugar, of which 65% (calculated on the weight of masse-cuite) is crystals; now, if all these crystals be recovered in one operation, the percentage recovery on total sugar is evidently 81.25%. In actual practice, however, only 56% of the weight of the masse-cuite was recovered, indicating a recovery on total sugar of 70%. There remains of first molasses or second masse-cuite 44% of the original masse-cuite, provided the water content has not been altered. The sugar content of this masse-cuite will be 54.5%: it will contain nine parts on the original weight or 20.4% on the second masse-cuite as crystals. In actual practice, from 20% to 25% of low grade crystals containing about 88% sugar may be expected to be recovered in the turbines; allowing a recovery of 20.4%, the total recovery will be on the original masse-cuite the original 65% of crystals, but as the crystals in the second sugar only form from 80% to 85% of the crude low grade product, still crystals have passed away which may be recovered in a third boiling. These figures are based on ones actually obtained in practice.

On the other hand, let there be a purer masse-cuite containing 85% of total sugar and only 65% of sugar as crystals, the researches of Geerligs having shown that in general a high polarisation does not indicate a high percentage of sugar as crystals. In this case if all the

crystals be recovered, the percentage recovery on total sugar would be 76.4%; but it is well known that the purer the juice or masse-cuite the greater the recovery, and that by continued reboiling of the molasses, final molasses of sugar content the same as those obtained from impurer juices are produced, a result equally well obtained by return of the molasses to first masse-cuites. By the continued addition of lime the conditions of the solubility of sugar in the mother liquor which was originally saturated must be altered, so that when the molasses are re-boiled sugar is precipitated, else the percentage recovery with pure juices would be lower than with impure ones.

CHAPTER XVIII.

GEERLIGS' THEORY OF MOLASSES.—OSMOSIS.—SUBSTITUTION PROCESSES.—THE MOLASSES PROBLEM.

The chief factor in the formation of molasses was formerly considered to be the viscosity of the syrups preventing free movement of the sugar molecules; this theory fitted in with the knowledge that in beet molasses the sugar content was higher than in a saturated aqueous solution containing the same amount of water; in cane molasses the reverse is generally the case. This observation is alone sufficient to invalidate the older theory, known as the mechanical theory of the formation of molasses. The whole subject has been the object of a classical research by Geerligs (*Sugar Cane*, Nos. 284-292, 311-313).

Geerligs introduces his subject by a discussion of the methods of analysis of molasses, and shows—

1. The method of direct polarisation gives results that may be too high or too low.
2. Clerget's method gives results agreeable with those obtained by determinations of glucose before and after inversion.
3. The glucose present has a lower lævo-rotation than that due to pure invert sugar.
4. The glucose present is not inactive at 88° C., the temperature at which the activity of invert sugar vanishes.

Of earlier experimenters Gerard and Laborde (*Zeitschrift für Rübenzuckerindustrie*, 1876, 399 and 402), and also Müntz and Hulze (*loc. cit.*, 1878, 735) found glucose from cane sugar inactive; Gunning (*Saccharimetrie in accijns*) and Meissl (*loc. cit.*, 1879, 1040) found the rotation of glucose in cane molasses the same as for invert sugar.

Herzfeld (*loc. cit.* 1885, 967) and Wehne (*loc. cit.* 1888, 785) found the glucose to consist of varying quantities of dextrose and levulose. The last result is the one to which Geerligs came; in his results it is always the dextrose which is present in the greater proportion, and accordingly it is quite possible for the mixture to be optically inactive. After having made complete analyses of a number of molasses, Geerligs reviews the results of earlier investigators. Marschall (*Zeitschrift*

für Rübenzuckerindustrie 1870, 339; 1871, 97) determined the effect of the presence of salts that occur in beet molasses on the solubility of sugar; he found that sugar was more soluble in the presence of either acetate, butyrate, carbonate or citrate of potash, but that all other salts had no effect or diminished the solubility. Felz (*loc. cit.* 1870, 337; 1871, 167) adhered to the mechanical theory, holding that the viscosity of molasses prevented crystallisation; this mechanical theory was disproved by Geerligs who found that the maximum amount of sugar crystallised out from solutions made thick with glue or agar-agar, the viscosity being much greater than in molasses.

Gunning (*loc. cit.*) formed artificial molasses by admixture of pure sugar and solutions of alkaline organic salts; he found that potash salts formed with sugar syrupy combinations which did not crystallise and deduced the formation of a saccharate of potash; he gave 6.1 as the molasses-forming co-efficient of potash, *i.e.*, one part of potash (as KOH) prevents 6.1 parts sugar from crystallising; for acetate of potash the figure would be 1.5 allowing only half the potash to affect the sugar, the other portion remaining as an acid salt.

It had been previously stated by nearly all writers that glucose was melassigenic; the co-efficient had been placed by Pellet at 0.60, by Flourens as between 0.30 and 1.0, Degener declaring that glucose had no direct melassigenic property but that the acid products of its decomposition inverted sugar. Geerligs made a series of experiments to test this statement. As a source of glucose he used honey in which the dextrose and levulose are present in about the same proportion as in molasses; he thus was able to prepare a series of solutions in which the water and sugar were constant but the glucose varied from nothing up to 25 grams; the sugar present was always 25 grams and the water 7.5 grams. It was found that the sugar crystallizing out was always the same and that the glucose had no effect and hence was not melassigenic. Geerligs next tried the effect of the presence of acetate of potash and the combined effect of this salt and glucose; he found that one part of acetate of potash per 25 of sugar had no effect, with two parts the effect was noticeable, and very marked with five parts; but when one part acetate of potash and 10 parts glucose were present per 25 parts sugar the combined effect was anti-melassigenic, *i.e.*, more sugar crystallised out than from water alone, and it was not till five parts acetate of potash and ten parts glucose were present that the combined effect was melassigenic. In later papers on the subject Geerligs returns to the effect of glucose

on the crystallisation of sugar and suggests that glucose forms with organic potassium salts easily soluble syrupy bodies which absorb water and render the proportion of sugar to water lower than normal; this point is entirely supported by his analyses when the ratio of glucose to alkalinity of the ash as potash is considered, the alkalinity of the ash as potash being a measure of the organic salts present, such a salt as acetate of potash giving on incineration carbonate of potash. As a general and well-marked rule, Geerligs found that when the ratio of glucose to alkalinity is low, *i.e.*, when there is much glucose and little alkalinity, that the solubility of sugar in molasses is greater than when the reverse is the case. A further point brought out by the analyses is that when a large proportion of undetermined constituents occurred the solubility of the sugar was low, the undetermined bodies being probably substances of similar constitution to glucose and acting in the same way.

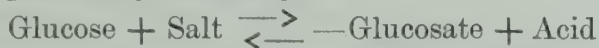
To further test the results found on a study of natural molasses Geerligs formed artificial molasses out of sugar, purified honey and various salts; the salts employed were the acetates of potash, soda and lime, the apoglucينات* of the same bases, inorganic salts such as the chlorides and sulphates, and mixtures of organic and inorganic salts. The method of experiment was that the calculated quantities of sugar, honey, salt and water were put into large flasks, sterilised at 100° C., plugged with cotton wool and allowed to crystallize. The following results were obtained: solutions with acetates only produced no inversion, those with apoglucينات produced little inversion; solutions with inorganic salts always inverted and the inversion was greatest when the quantity of glucose was greatest;† when organic salts and inorganic salts were present the inversion was much less than in the immediately preceding case. The results already obtained with regard to the solubility of sugar in the presence of other bodies were completely confirmed and in addition it was found that the sugar-precipitating power of the organic salts was greatest in the order lime, potash, soda.

The inversion of sugar by the combined effect of glucose and salts was then investigated; it was found that glucose *per se* had no inverting effect but that in the presence of salts, organic or otherwise, it had. Geerligs explains these experimental phenomena in these words, “ . . . *the entire action of molasses forming is explained by the*

* The decomposition products formed on heating glucose with lime.

† The solutions were always neutral.

assumption that both sugar and glucose, and those products of decomposition of the latter which resemble caramel, have a tendency to combine with the bases of the salts, and hence to a certain extent act as acids." This statement is in entire accord with the theories of Van't Hoff expressed symbolically as



i.e., if glucose and salt occur together in solution they are mutually to a certain extent dissociated; the same equation holds equally for saccharose.

In accordance with this equation, if saccharose and an organic salt are present together, they are both to a certain extent dissociated, and the saccharose forms with the base a very soluble hygroscopic compound, and hence is explained the abnormal solubility of sugar in beet molasses, which contain but little glucose. When glucose* is present along with saccharose, the glucose possessing an aldehyde group is more readily split up, and forms with the bases similar compounds to the above, and extracting water has the effect of lowering the solubility of saccharose, as is the case in cane molasses. When the carbonatation process is used the glucose is in great part destroyed, and saccharose is found more soluble in carbonatation than in defecation molasses. When glucose and an organic salt are present their mutual dissociation forms free acid and causes inversion, but the inverting power of organic acids being small the inversion is not great. When glucose and an inorganic salt are present the same reaction occurs, and the inversion is greater for the reverse reason.

When glucose, organic and inorganic salts are present, the combined effect is chiefly that due to the organic salt, and the effect of the inorganic salt is modified.

The process of inversion of cane sugar under the combined influence of acids and salts is different to that for acid inversion alone, and is explained by the recently developed electro-chemical theory of solutions, one of the points established in that theory being that a weak acid is greatly weakened by the addition of its own neutral salts. Herein lies the explanation of the well-known observation that juices can be worked up with an acidity (phosphoric) represented by from 1.5 to 2.0 normal per 100 c.c. without any inversion occurring. In the case of a cane juice in addition to the free phosphoric acid neutral phosphates are also present in the juice; so

* In glucose is included its undetermined decomposition products.

great an acidity in the case of sugar and acid alone in solution would result in inversion.

The causes tending towards the formation of molasses may be summarised—

1. The presence of non-sugar requiring water for its removal, such water carrying away sugar.
2. The formation of molecular compounds consisting of sugar and organic salts, chiefly potash salts.
3. Inversion under the influence of acids as when working with phosphoric acid and under the combined influence of glucose and salts, chiefly inorganic salts.
4. An excess of lime acting on glucose, originally present and giving rise to organic salts, which then act as in (2) and (3).
5. Viscosity of syrups resulting in formation of fine grain which passes through the centrifugal.
6. Careless pan boiling, resulting in fine grain, requiring much water in the centrifugals.

As tending to prevent the formation of molasses Geerligs indicates but does not recommend the use of baryta, inclining more to the carbonatation process, and when the usual defecation process is used he recommends—

1. Use as little lime as possible in defecation but of course enough to get a good clarification.
2. Prevent by rapid working and cleanliness every source of acidity, because if juices get sour they require fresh quantities of lime to neutralise the acid and therefore fresh quantities of salts are produced.
3. If any excess of lime has been used, remove it by the use of phosphoric or sulphurous acids which decompose some of the organic acids and precipitate the lime.
4. Extract the salts from the after products by putting the latter under water.

The decomposition of glucose in the carbonatation process gives rise to large quantities of organic salts and hence in carbonatation molasses the sugar solubility is high; this is counterbalanced by the less quantity of molasses formed.

No definite figures can be given for the composition of molasses; the sum total of the sugar and glucose is generally between 55% and 60%, but, in the carbonatation process for the reasons already given, rises considerably higher. The following table is abstracted from the analyses made by Geerligs for the construction of his theory:—

Sugar.	Glucose.*	Ash.	Water.	Alkalinity of Ash as K ₂ O.	Glucose : Ash.	Glucose : Alkalinity of Ash as K ₂ O.	Sugar† per 100 Water.
Per cent.	Per cent.	Per cent.	Per cent.				
59·20 _a	7·29	6·07	25·12	1·13	1·22	6·40	235·6
50·20 _a	15·14	4·35	25·31	1·30	3·48	11·47	198·3
42·90 _a	19·93	3·00	28·93	·34	6·64	23·45	148·6
33·70 _a	28·12	3·65	24·50	1·01	7·70	27·30	145·7
47·90 _b	17·44	7·00	16·45	3·85	2·49	4·53	291·1
39·90 _b	18·50	7·00	24·40	3·24	2·64	5·11	163·5
34·11 _b	28·60	5·30	23·46	3·05	5·40	9·50	144·5
30·90 _b	27·47	6·37	24·14	2·63	4·31	10·40	128·0
22·42 _b	34·50	3·30	26·07	1·10	10·46	31·30	86·0
43·70 _c	15·80	6·50	17·10	2·75	2·43	5·70	255·6
38·40 _c	21·00	5·41	27·90	2·72	3·88	7·70	138·3
32·40 _c	23·00	5·20	28·60	2·25	4·42	10·20	113·3
23·94 _c	40·00	5·30	18·00	2·78	7·55	15·00	133·0

a First molasses. *b* After molasses. *c* Worked out molasses.

Besides the sugar, glucose, water, and ash, Geerligs determined in exhausted molasses all the other constituents, and found from 8·3% to 22·9% of dextrose; from 5·6% to 16·5% of levulose, the dextrose being always present in larger quantity than the levulose; from 1·95% to 6·25% of soluble ash; from ·99% to 5·30% of insoluble ash; the ash containing from ·74% to 3·51% potassium carbonate, ·15% to 3·37% potassium sulphate, 0·0% to 2·30% potassium chloride; ·06% to ·59% sodium chloride; ·40% to 3·80% calcium carbonate; 0·0% to ·52% calcium sulphate; ·05% to ·83% calcium phosphate; ·05% to 1·75% magnesium carbonate; 0·0% to ·241% silica; 0·0% to ·54% free acid as acetic; ·68% to 2·5% pectin; 1·30%—3·99% of malic, succinic acids; 0·0% to 6·28% glucinic acid, but no citric acid, lactic acid, dextran, dextrin, or galactan.

To saccharic acid which had previously been described by Winter under the name of cannic acid he gives the formula C₁₄H₁₈O₁₄ and identifies it as a hexabasic acid; glucinic acid which is present in large proportion decomposes on evaporation, giving off acetic acid and carbon dioxide, and Geerligs suggests that herein may lie the

* Sum of dextrose and levulose.

† Normal solubility at 82·5° F. per 100 water, 213·5.

explanation of the foaming fermentation of molasses and after products.

It follows from what has been written above that if the salts could be removed from an exhausted molasses, the conditions of solubility of the sugar would be altered and a further portion would be capable of crystallisation. About 1850 a method of effecting this was worked out by Dubrunfaut. The principle of his process known as *osmosis* is as follows: if a concentrated solution of any soluble body be separated from a weaker solution or from water by a semiporous membrane, such as parchment, the two solutions will pass through the membrane until they are of the same concentration. The rate at which this osmosis or diffusion takes place is not the same for all bodies; inorganic salts such as potassium chloride diffuse much faster than sugar; hence if a solution of

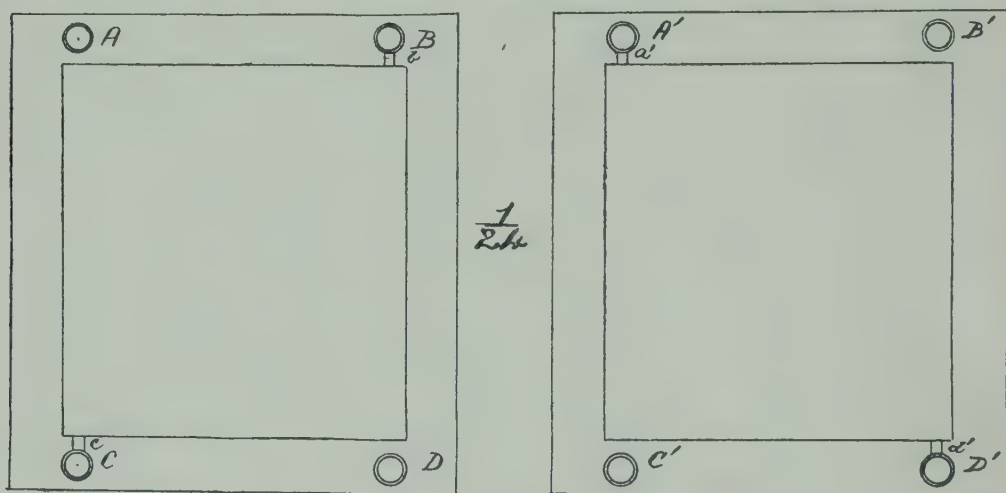


FIG. 90.

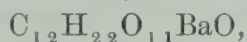
molasses be separated by a parchment membrane from water, a greater proportion of salts will pass through the membrane in a given time than sugar. An osmogene is an apparatus to effect this separation; it consists of a structure similar to a filter press in which are held a series of wooden frames, shown in elevation in *Fig. 90*. Between each frame are placed sheets of parchmentized paper, pierced at the angles to correspond with the apertures shewn at A, B, C, D, and at A', B', C', D', in *Fig. 90*. At *b* and *c* in the one frame and at *a* and *d* in the other, are small channels establishing communication with the interior of the frame. If, then, water enters at B and molasses at D, the water will flow along the canal formed by the openings B and into the interior of the frames by the channels *b*, and the molasses will similarly flow by way of D and *d'*. The water will

discharge itself along the canal formed by the openings C and c, and the molasses along that formed by the openings at A' and a'. There is thus a continual flow of molasses and water separated by a sheet of parchment. The water which leaves the apparatus now charged with a proportion of molasses is called water of exosmose, and it contains roughly about half the salts originally present in the molasses. Although this process has been largely used in times past and is still to a certain extent employed in beet sugar factories it is financially unsuccessful; the large size of the osmogenes required (500 square feet diffusion surface only being sufficient to treat three tons of molasses in twenty-four hours), the extreme dilution of the osmosed molasses, the expense of evaporation, and the small extra yield of sugar entirely discounting the monetary value of the process.

The Steffen and Scheibler substitution processes, although they cannot be worked in cane sugar factories owing to the simultaneous presence of glucose, are of such importance as to deserve a passing notice.

Cane sugar has the property of acting as a weak acid, and forming definite compounds with bases, more especially with baryta, strontia and lime; these bodies are known as saccharates.

With baryta, one saccharate only is formed:—

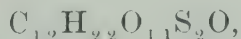


formed on heating a mixture of a solution of baryta and sugar when the saccharate is obtained as a crystalline precipitate; it is soluble in 41 times its weight of water at 15°C.

With strontia, two saccharates are formed. On mixing two molecular proportions of strontia with one of sugar in a boiling solution, the bibasic saccharate

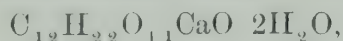


results and on cooling this body decomposes into the monobasic saccharate



and strontia.

With lime, four saccharates are formed; the monobasic saccharate,



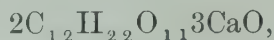
is formed by mixing molecular proportions of lime and sugar. This body is soluble in the cold, and is precipitated from aqueous solution by alcohol.

The bibasic saccharate,



is formed by mixing a double molecular proportion of lime with one of sugar. It is soluble in 33 times its weight of cold water.

The sesquisaccharate,



is obtained by pouring an excess of milk of lime into a dilute solution of sugar and evaporating to dryness.

If a solution of the bibasic saccharate be boiled it is decomposed, giving the tribasic saccharate



sugar and the bibasic form.

On these reactions are based the commercial processes for the extraction of sugar from exhausted molasses.

The first processes were those of Schleibler (1865) and Segferth (1872). In these processes molasses and slaked or quicklime were intimately mixed in a pug mill, and the resulting magma of saccharate and molasses washed with alcohol to remove the salts and organic non-sugar, and the purified saccharate mixed with the juice and carbonated. Many mechanical improvements were introduced by Bodenbender and Manoury, the former obtaining the saccharate in the form of cakes and the latter as grains. In both cases denaturated alcohol (duty free) is used, the alcohol being recovered for use. Over 90% of the sugar in the molasses is extracted at an average cost of 2s. for every 100 lbs. of molasses treated.

The original substitution process of Steffen eliminates the use of alcohol and is based on the behaviour on boiling of the mono- and bibasic lime saccharates. The five operations in the process are:—

1. Formation of a soluble bibasic saccharate in the cold.
2. Transformation of the bibasic saccharate into sugar and insoluble tribasic saccharate by boiling.
3. Separation by filtration of the tribasic saccharate.
4. Regeneration of the mother liquors by the addition of fresh molasses.
5. Periodic reduction of the mother liquors.

In outline the different processes are worked as follows:—

1. Molasses diluted to 11°-12° Balling are mixed with continual agitation with powdered quicklime in the proportion of one part sugar to one of lime; the mixture is then filtered to remove scums.
2. The filtrate is heated for ten minutes in autoclaves to a temperature of 105° C.
3. The tribasic saccharate formed in (2) is filtered, the cakes washed

with boiling water, and the saccharate employed in place of lime in treating the raw juice.

4. The mother liquors coming from (3) are used to dilute a further quantity of molasses to a sugar content of 6%.

5. After a time the mother liquors are so charged with impurities as to render them too impure to return; they are then treated separately, two operations sufficing to almost completely exhaust them. The mother liquors are returned about 25-30 times, after which the process commences afresh.

The cost of this process is only about 1s. per 100 lbs. of molasses, a recovery of over 90% of the sugar in molasses being obtained.

The second more recent process of Steffen considerably modifies and simplifies the above process.

It consists of three parts :

1. Preparation of a very pure finely divided quicklime.
2. Formation of a tribasic saccharate insoluble in the cold.
3. Extraction and purification of the saccharate.

In preparing the quicklime, a very pure non-siliceous limestone is selected which is burned out of contact with the fuel (see Chapter XI.); the burnt lime is broken up in a stone-breaker and passed through a series of sieves to obtain it in the necessary fine state of sub-division.

In the second operation the molasses diluted to a density of 10°—12° Balling are cooled down to a temperature lying between 0° C. and 13° C., and generally to a temperature of 6° C., and quicklime added in small quantities about 10 lbs. at a time until 210 parts of lime are added per 100 of sugar; during the whole operation the molasses are continually agitated and the temperature is not allowed to rise above 13° C.; at the end of the process, which lasts about three quarters of an hour, there is obtained a pasty mass, consisting of a mixture of tribasic saccharate and slaked lime.

The third operation consists of separating the saccharate by filtration and washing with cold water; the filtrate which contains practically all the impurities is rejected, the washings being used to dilute a further quantity of molasses; the purified saccharate is either used in place of lime on raw juices or is treated separately by carbonatation. The cost of working this process is only about half that required for the older Steffen process.

The discovery of large deposits of strontianite in Westphalia opened the way to the use of this material in extracting sugar from molasses. Two processes, both due to Scheibler, are in use.

1. *Bibasic Process*.—In this process three equivalents of strontia to one of sugar are added to a hot diluted molasses, and the saccharate which forms is separated from the mother liquors by filtration and washed with a 10% solution of strontia; all these operations are done when still warm. In order to decompose the saccharate, it is placed in vessels set up in a battery, through which is passed water at a temperature of from 4° C. to 15° C., the water containing 2% of strontia; by these means the bibasic body is decomposed into the monobasic saccharate and strontia; this operation takes about forty-eight hours. A solution of sugar still containing strontia passes out from the diffusers and is treated by carbonatation.

2. *Monobasic Process*.—In this process a solution of strontia is mixed with the molasses, the temperature not being allowed to rise above 20° C.; the monobasic body is formed, which is separated by filtration and treated as already described by carbonatation.

To both these processes the recovery and regeneration of the strontia by ignition in special furnaces forms an important factor in the economy of the process.

The disposal or utilisation of the refuse molasses is a problem of growing importance. Four principal methods are in use.

1. *Conversion of the Molasses into Alcohol*.—A very large proportion of cane molasses are thus utilised, especially in the West Indies and Peru. In Java excise regulations are prohibitive, and in Mauritius absence of a market other than a small local one prevents any extended output. For estates that can make a finely-flavoured spirit this method allows large profits, but for others the financial results are often very poor. The growing use of denaturated alcohol for small motors, lighting, heating and cooking purposes, promises to open up a remunerative market.

2. *Sale as Cattle Food*.—This process has been developed under the *Molascuit* patents of Mr. G. Hughes. The interior pith fibre of the cane, of which 75% is digestible, and possessing great absorptive powers, is mixed with final molasses, a meal capable of being packed in bags resulting. About one part of megass is required for three of molasses. In practice the megass from the mill passes over an

oscillating sifter and the fine particles falling through are partially dried either in special plants or more economically by waste heat from the flue. The fine megass is then mixed in a kneading machine with the requisite quantity of molasses and is then bagged for shipment.

3. *Utilisation as Fuel*.—In many cases this method forms the most practical way of disposal of the molasses where, for some cause or other, rum cannot be profitably made. The fuel value of molasses and the methods of burning it are discussed in a subsequent chapter. The molasses usually contain large quantities of potash, which is recoverable in the ashes for use as manure.

4. *Return to the soil*.—In relation to agriculture this method forms the best system of disposal; where the waste waters from the factory are used for irrigation purposes, the molasses are, without expense, disposed of. In Mauritius, they are very often mixed with the heaps of farmyard manure made by the stock on the estate.

CHAPTER XIX.

MEGASS AS FUEL.

The battery of boilers and its connections form one of the most important parts of any factory and are of particular interest in a sugar works in view of the evaporation produced by the steam here generated, in addition to that required to supply motive power to the engines; efforts to economise steam within the factory are in great part useless unless economy is also practised in the combustion of the fuel. The subject of boilers as such is a special one of its own and its discussion is quite outside the limits of a work such as the present; only a few points of special interest in the sugar factory are here mentioned.

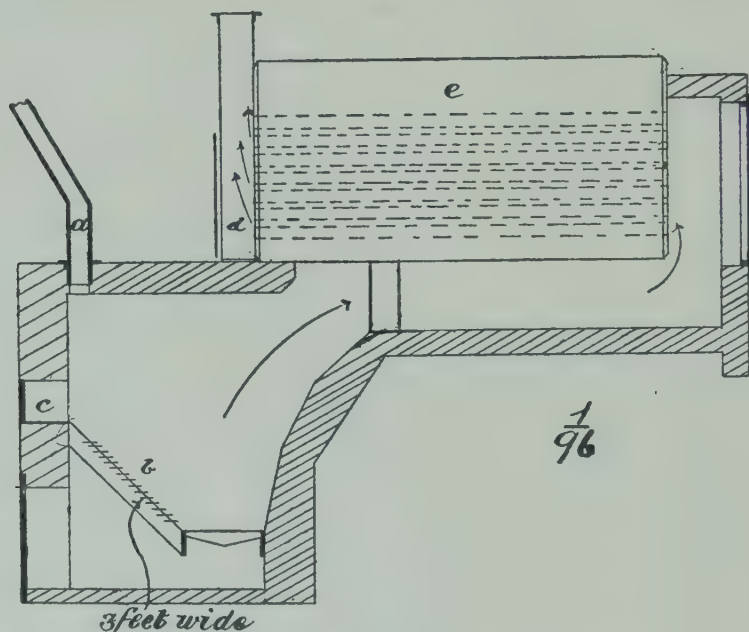


FIG. 91.

Boilers may be divided into a number of classes such as external and internal fired boilers; the former class includes the multitubular boilers in very general use in sugar factories, the flue boilers such as the Lancashire falling into the latter category. These last are quite unsuited for the combustion of megass and similar fuels, and the majority of boilers to be found in sugar factories are multitubulars,

although in late years in many cases they have been replaced by water tube boilers. The multitubular boiler consists of a cylindrical shell having a length generally about twice the diameter; thus sizes 14 ft. $\times$ 7 ft. or 12 ft. $\times$ 6 ft. are frequently met with. The boilers erected at the Puunene mill in Hawaii in 1902 were however 20 ft. $\times$ 7 ft.; a length such as this is objected to by some engineers on the grounds that the part of the boiler remote from the furnace is very ineffective.

In the end plates of the shell are drilled a number of holes into which are expanded tubes generally about four inches in diameter; these tubes form the greater part of the heating surface and are for the sizes quoted about 100 in number. A boiler 14 ft $\times$ 7 ft. with 118 tubes will have 1,800 sq. feet heating surface; increasing the length to 20 feet will give a heating surface of 2,600 sq. feet.

A section of a multibular boiler and furnace is shown in *Fig 91*. The boiler is seen at *e*; the direction of the flue gases arising from the combustion of the megass upon the grate *b* is first along the bottom and sides of the boiler, then back through the tubes and out to the smoke box *d* and thence to the main flue. Megass from an overhead carrier enters by the shoot *a*; a door for hand firing is shown at *c*. This furnace is called a *Dutch oven*, and as shown a large combustion chamber is provided; occasionally furnaces of this type are seen in which the grate is brought much nearer to the boiler, so that the combustion chamber almost disappears.

In *Figs. 92 and 93* is shown what is known as the *Abel* type of megass furnace; this is intended for overhead firing. Megass direct from the mill is fed into the shoot *a*; the platform *i* serves as storage room for a supply of megass; the latter may be raked by hand to the shoot or delivered automatically; but the most generally adopted method is to convey the megass by a scraper carrier on a platform erected over the hopper. Over each hopper is an opening, the size of which is controlled by a shutter and the quantity of megass delivered to each furnace easily regulated. From the shoot the megass falls on to the firebars at *b*; these are generally set at an angle of 45° or thereabouts; the gases formed on combustion impinge on the arch at *e*. The air necessary for combustion enters at *f*, the space *k* forming a hot air reservoir; the ashes are removed at *i*. The boiler is shown at *c*; the passage of the gases is first through the tubes, thence to the smoke box *h*, back along the sides and out underneath the boiler to the main flue *g*. In this design the flue gases pass three times along

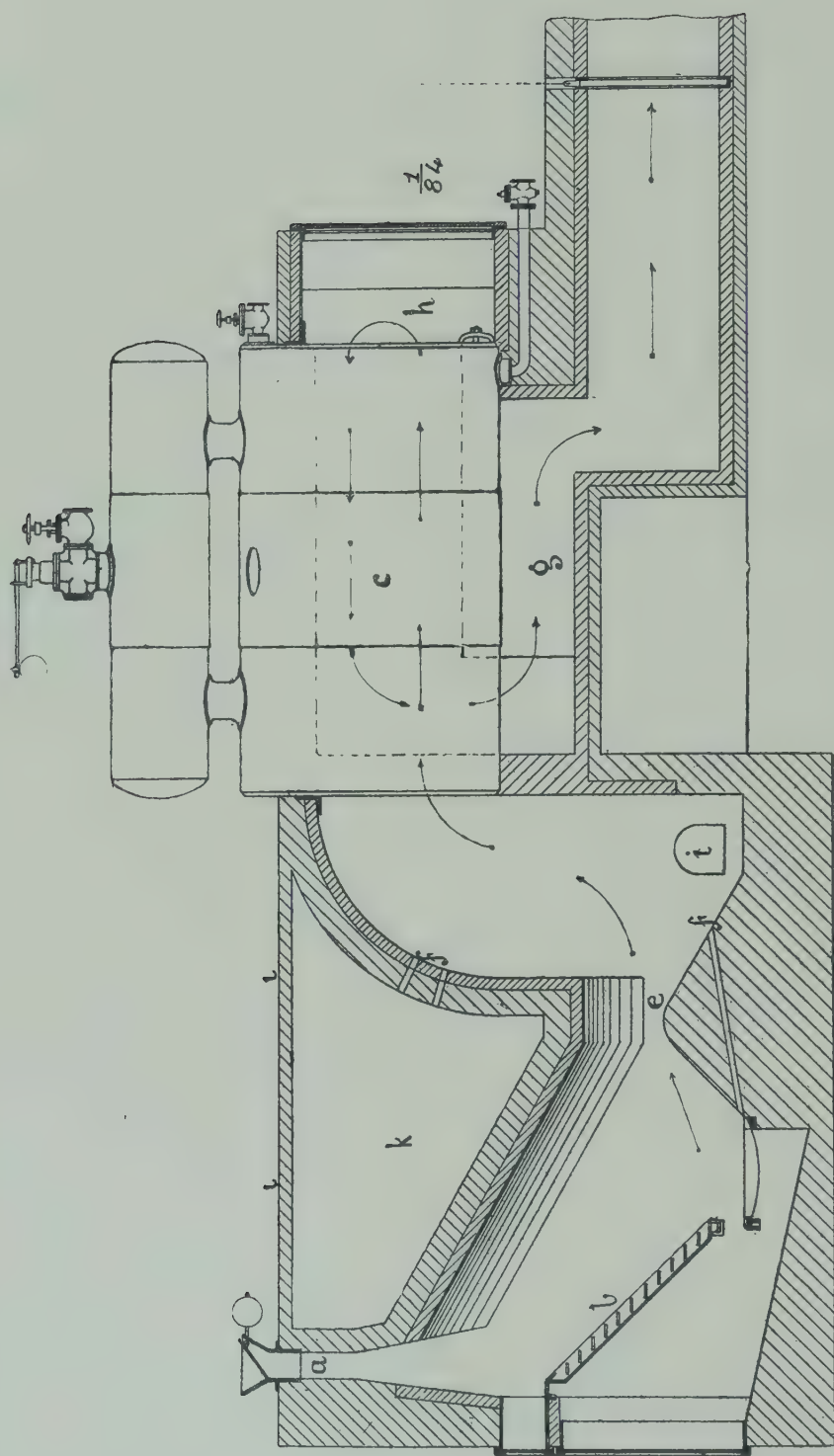


FIG. 92.

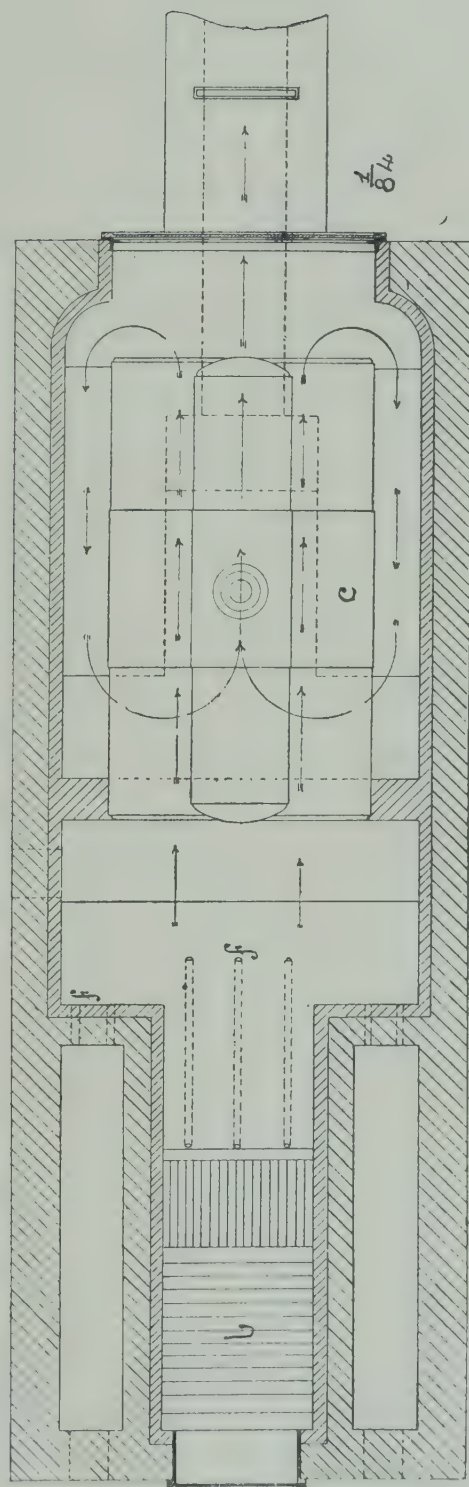


FIG. 93.

the boiler as opposed to the two way pass in *Fig. 91*. Very frequently the gases are first passed underneath the boiler, for the reason that the greatest temperature being applied where the water is densest, the circulation is benefited.

The *Godillot* furnace, *Fig. 94*, is a furnace of the Dutch oven type. The megass enters at *b*, being propelled forward mechanically by the screw *c*; the firebars are arranged so as to form three sides of a pyramid shown at *d*; air enters at *e*, and at *f* is an aperture for viewing the combustion.

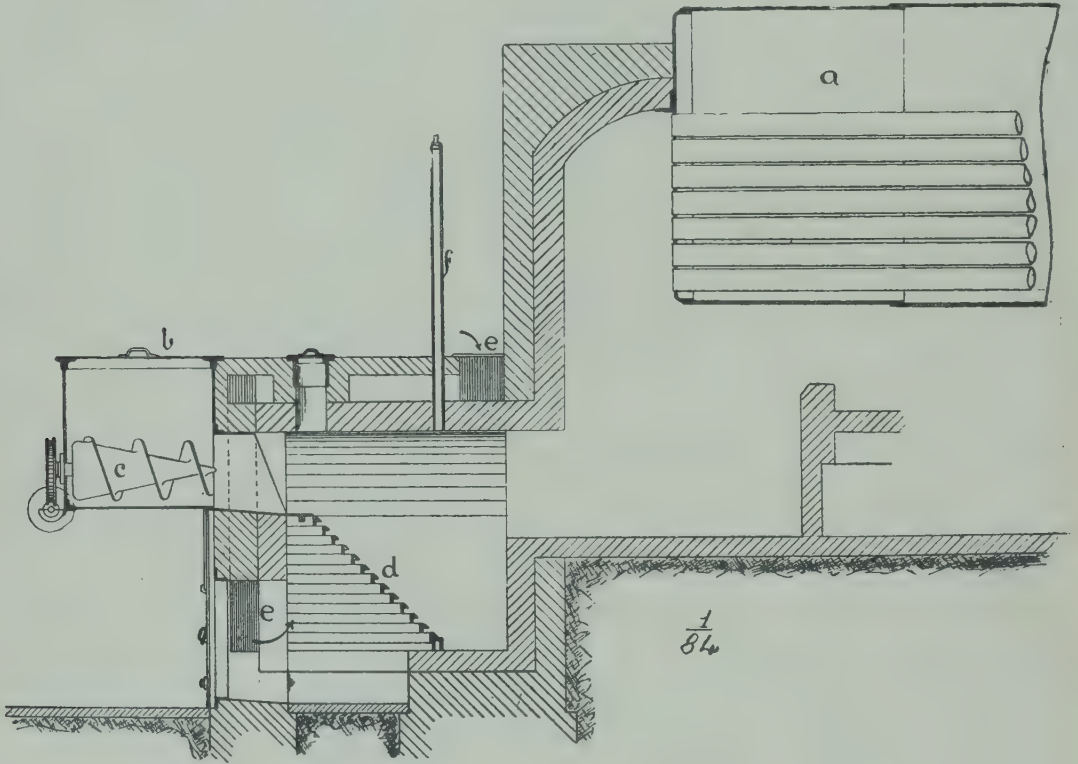


FIG. 94.

The water tube boilers, which have in recent years been largely installed in sugar factories, possess the following points: Steam is raised more quickly, and also falls more quickly; they are well adapted for high pressures, and are easily transported; they are more expensive in first cost than multitubulars, but much larger units can be installed, thus economising labour. In treating of the choice of boilers for a sugar factory, the late Hugo Jelinek wrote: "In a sugar factory, a type of boiler is to be chosen which has a large water capacity, so as to have always a provision of heat for unequal consumption of steam in the factory." The adoption of water tube boilers is in direct opposition to this dictum; the lack of water

capacity in this type may at times become a positive nuisance in a sugar factory, as, owing to it, any sudden load put on the boilers may result in a sudden drop in the steam pressure. Such a load may occur when starting a pan with cold syrup; the difficulty is not so great, however, as not to be overcome by careful control.

The following dimensions have been found suitable for megass combustion:—

Ratio of grate area to heating surface at the Puunene factory in Hawaii was originally 1 : 63 and was afterwards reduced to 1 : 53; Abel* used a ratio of 1 : 65 with satisfactory results.

At Puunene 87 lbs. of megass were burnt per square foot of grate area per hour, Abel's figures giving a consumption of 84 lbs.

With water-tube boilers a lower ratio of grate area to heating surface seems to be satisfactory, a furnace with a ratio of 1 : 110 being a figure very commonly adopted in modern practice.

The combustible bodies present in megass are the fibre, sugar, glucose, and details of other organic bodies; the megass resulting from different canes will have very different thermal values, which depend also to an equal extent on the method of treatment in the mill. In discussing the thermal value of megass not only must different types of cane be considered, but also the treatment they receive at the mill, the sugar content of the juice, and its mode of treatment. Following on three types of canes, two methods of mill extraction and subsequent working up are considered. The types of cane discussed are: one of poor, one of average, and one of higher fibre content; the methods of juice extraction are dry double crushing, and treble crushing, with dilution 10% on the canes; for a subsequent working up of the juice two methods—one not strictly economical in steam, and one of strict economy—are considered.

In calculating the composition of juice and megass it has been uniformly assumed that the canes are crushed to a fibre content of 42%; the resulting quantities and composition of juice and megass from the assumed composition of the different types of canes is shown in the annexed table. After having obtained the quantity and composition of the megass, the next step is to calculate its thermal value; direct experiments to determine the heats of combustion of fibre, sugar and glucose have been made by Stohlmann and Langbein, who have found that the burning of 1 lb. cellulose (fibre) gives on combustion 7533 B.T.U., the corresponding figures for sugar and glucose

* Proc. Inst. Civ. Eng., Vol. CXXIII., Part I., page 370.

TABLE GIVING THE COMPOSITION OF JUICE AND MEGASS RESULTING FROM CANES OF THE COMPOSITION
SHOWN UNDER DIFFERENT TREATMENTS.

	Type of Crushing.	CANES.				MEGASS PER 100 TONS OF CANE.					JUICE PER 100 TONS OF CANE.			
		Sugar. Per cent.	Water. Per cent.	Fibre. Per cent.	Other Matter Per cent.	Tons.	Sugar. Tons.	Water. Tons.	Fibre. Tons.	Other Matter Tons.	Tons.	Sugar. Tons.	Water. Tons.	Other Matter. Tons.
A	Dry double	15	73	10	2	23·81	2·30	11·20	10	·31	76·19	12·70	61·80	1·69
B	“	12	74·5	11·5	2	27·39	2·15	13·27	11·5	·37	72·61	9·85	61·13	1·63
C	“	9	76	13	2	30·95	1·85	15·67	13	·43	69·09	7·15	60·33	1·57
A'	Treble with 10 % added water.	15	73	10	2	23·81	1·33	12·29	10	·19	86·19	13·67	70·71	1·81
B'	“ “	12	74·5	11·5	2	27·39	1·24	14·34	11·5	·31	82·61	10·76	70·16	1·69
C'	“ “	9	76	13	2	30·95	1·07	16·48	13	·40	79·05	7·93	69·52	1·60

being 7120 B.T.U. and 6748 B.T.U. respectively. Since the thermal value of the megass A is then per lb. $\cdot 42 \times 7533 + \cdot 0966 \times 7120 = 3851$ B.T.U. for the fibre and sugar alone, to this must be added that due to the glucose and other organic matter which has been taken as $\frac{1}{10}$ of that due to the sugar, giving a gross thermal value for the megass of 3920 B.T.U. From this has to be deducted the heat required to evaporate the associated moisture; this enters the furnace at say 84° F. and leaves at temperatures varying from 400° F. to 600° F. Taking this temperature at 550° F., a very general figure, the heat carried away by each lb. of associated moisture is 1254 B.T.U., and in the case under consideration, there being 47% moisture in the megass, the loss here is 589 B.T.U., giving a nett thermal value to the megass in question of 3331 B.T.U.; results of similar calculations of other cases are given in the table on page 269.

(Before going any further, some points connected with the "fuel value" calculation call for notice. An old and incorrect method of obtaining the fuel value of a carbohydrate fuel was to calculate out the percentage of carbon and to assume that the fuel value was the same as this amount of carbon. Fibre contains 44.4%, sugar 42.1%, and glucose 40.0% of carbon; the carbon value of the megass already considered is, then, .232 lbs. carbon per lb. megass, allowing as before that the glucose and other organic bodies are in value $\frac{1}{10}$ of the sugar. The heat of combustion of carbon is 14,400 B.T.U., so that by this calculation the gross thermal value of the megass is 3340 B.T.U.

The fibre referred to in Stohlmann's and Langbein's determinations is digestible fibre and different to the crude quality present in megass, and an error of unknown but probably smaller magnitude may be introduced into the calculation for this reason.

Actual experiments with the calorimeter to determine the fuel value of megass made by H. N. Pharr, at the Vanderbilt University, gave fuel values which, on an average, exceeded the calculated value by 12%).

For the purposes of this chapter the *net fuel value of a megass is defined as the gross thermal value, less the heat necessary to evaporate, at the temperature of the flue gases, the associated water.*

Megass and all carbohydrate fuel give as products of combustion water vapour and carbon dioxide; it is held by some that the heat carried away by the water vapour formed on combustion, distinct from the water vapour due to associated moisture, should be deducted also from the gross fuel value to obtain the net fuel value of a carbohydrate fuel.

The products of combustion of a megass can be easily obtained; each pound of carbon on burning requires a theoretical minimum of 2·67 lbs. of oxygen, a quantity supplied by 12·03 lbs. of air, the remainder 9·36 lbs. being nearly all nitrogen; at a temperature of 84° F. this quantity of air occupies 165 cubic feet. The combustible elements in megass contain hydrogen and oxygen in the same proportion as they exist in water, so that in calculating the air required for combustion only the carbon need be taken into account. Taking the megass already considered as an example it will then require for complete combustion $\cdot 232 \times 12\cdot 03$ lbs. = 2·79 lbs. air and the flue gases produced per lb. of megass will consist of (not considering the associated water) ·851 lbs. carbon dioxide, 2·171 lbs. nitrogen and in addition the water formed on combustion; fibre gives 55·6% of its weight, and sugar 57·9% of water on combustion, and again allowing for glucose and other organic bodies $\frac{1}{10}$ that found for the sugar, the megass in question will give ·294 lb. water.

In general practice it is exceptional that less than twice the theoretical minimum of air necessary for combustion be used; assuming that exactly twice is used the products of combustion of one pound of the megass in question are—

1. Due to combustion of the carbon. ·851 lbs. carbon dioxide.
2. Due to excess of air, *a*, oxygen. ·517 lbs.
b, nitrogen. 4·343 lbs.
3. Associated moisture. ·470 lbs. water.
4. Combined water. ·294 lbs. water.

The heat carried away in the flue gases under working conditions may now be readily obtained. The specific heat of carbon dioxide at constant pressure is ·22; that of oxygen, ·22; and that of nitrogen, ·24. Taking the temperature of the flue gases as 550°F., each pound of water evaporated and carried away at this temperature from an initial temperature of 84°F., carries away 1254 B.T.U.

The loss of heat, then, with flue gases at 550°F., and an excess of air, is twice the theoretical.

Carbon dioxide . . .	·851 × ·22 (550—84) =	87 B.T.U.
Oxygen	·517 × ·22 (550—84) =	53 B.T.U.
Nitrogen	4·343 × ·24 (550—84) =	486 B.T.U.
Associated Moisture..	·470 × 1,144 =	537 B.T.U.
Combined Water	·294 × 1,144 =	337 B.T.U.

Total	1,500 B.T.U.
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a quantity which, when deducted from the gross thermal value found of 3921 B.T.U., leaves 2421 B.T.U. available for forming steam in the boiler, *i.e.*, 61·74% of the gross thermal value.

There are, in addition, other losses, the exact magnitude of which little is known, and they are the losses in unburnt fuel, hot ashes, and in radiation, so that on an average not more than 55% of the gross thermal value of the megass is utilised in raising steam.

In the following table are calculated the gross thermal values, the net thermal values, and the heat available for generating steam estimated at 55% of the gross thermal value, and the pounds of steam from and at 212° F. for the six types of megass considered.

Type of Canes and Crushing.	Sugar.	Water.	Fibre.	Other Solids.	B.T.U.			Lbs. Steam from and at 212° F. per lb. Megass.
					Gross Thermal Value.	Nett Thermal Value.	Available for making steam at 55% of gross.	
	Percent.	Percent.	Percent.	Percent.	Per lb.	Per lb.	Per lb.	
A	9·66	47·04	42	1·30	3920	3331	2156	2·23
B	7·85	48·81	42	1·34	3779	3167	2078	2·15
C	5·99	50·63	42	1·38	3634	2999	1999	2·07
A'	5·58	51·62	42	·90	3601	2954	1980	2·05
B'	4·52	52·36	42	1·12	3518	2861	1934	2·00
C'	3·46	53·25	42	1·29	3435	2767	1889	1·95

From the value per pound of fuel, the thermal value and the steam generated per 100 tons of cane can be at once calculated, and an estimate made as to how far the megass will go towards working the factory. In the annexed table are given results for the six types of mill work, combined with two methods of working in the factory; the one may be taken as a process economical of steam, and the other as uneconomical but still very general. In the first case the juice is evaporated in a quadruple effect without any cleaning in open pans, and molasses are reboiled along with the first massecuite without dilution; in the second case juice is cleaned in open pans and evaporated at triple effect, and molasses are reboiled after dilution. The methods used in the calculations are explained below.

Heating Juice to 212° F.—The specific heat of the solids has been taken as ·301, being that of sugar, the solid present in the largest proportion.

Re-heating Juice.—The details of manufacture require that the juice cool in the passage from the clarifiers to the evaporator ; it is assumed that it cools to 160° F. and is raised in the first vessel of the effect to 203° F.

Cleaning in Open Vessels.—When making consumption sugars, in removing scums in the eliminators the juice is concentrated through as much as 1.5°—2° Balling and an evaporation of 10% has been assumed, each pound of water evaporated being taken as requiring 1150 B.T.U.

Evaporation in Effect.—If B_1 be the degree Balling of the juice entering the effect and B_2 the degree Balling of the syrup, the evaporation per cent. by weight on original juice is $\frac{B_2 - B_1}{B_2} \times 100$. In the triple, for each pound of water evaporated 350 B.T.U., and in the quadruple 290 B.T.U. are assumed necessary ; the density of the syrup is taken as 55° Balling.

Evaporation in Pans.—The masse-cuite is assumed to be concentrated to 96° Balling, the calculation of water removed being made on the same lines as for syrup.

Evaporation of Molasses.—The molasses are taken as 40% of the weight of the masse-cuite and to be of density 88° Balling ; they are diluted to 50° Balling and re-boiled to 92° Balling.

Engines.—The steam used in the engines is in great part saved for further use in the evaporation. To calculate the heat used in the simplest form, the amount of steam passing into the cylinders of the engines, together with the initial and exhaust pressures, must be known ; for instance, in the case of a non-condensing engine taking steam at 80 lbs. per square inch and exhausting at 8 lbs., the total heat of one pound of steam at 80 lbs. is 1180.8 B.T.U., and at 8 lbs. is 1153.8 B.T.U. ; so that only 27.0 B.T.U. have been used in motive power and the rest is available for evaporation.

In the cylinder, however, a very considerable proportion of the steam is condensed and is not available for evaporation. Its amount varies with the cut off ; in single non-condensing engines with cut off at 5% of the stroke, about 40% of the steam is condensed, decreasing to about 15% when the cut off is at half-stroke.

To find the amount of steam used by an engine the simplest method is first to obtain the indicated horse power. This is given by the well-known formula :—

$$\text{I.H.P.} = \frac{2PLAN}{33,000};$$

where P = Mean pressure in lbs. per sq. in.
 L = Stroke in feet.
 A = Area of piston in square ins.
 N = Number of revolutions per minute.

To find the mean pressure on the piston, let

p = the absolute initial pressure ;
 p_1 = the absolute back pressure ;
 r = the ratio of expansion ;
 p_m = mean pressure.

Then

$$p_m = p \left(\frac{1 + \text{hyp. log } r}{r} \right) - p_1$$

Non-condensing engines take very different amounts of steam per I.H.P. hour; the very best engines working under good conditions may take as little as 18 lbs., a quantity which may rise to as much as 40 lbs. On an average, a consumption of 25 lbs. to 30 lbs. may be taken as general. In the annexed table, which was calculated from data obtained in an average modern factory, the I.H.P. of the engines was obtained as indicated above, and a steam consumption of 25 lbs. per I.H.P. hour, together with a cylinder condensation of 20%, are taken as representing average work.

Losses in Steam Pipe.—The latest experiments of German origin show a loss per sq. metre of about 3 kilos of steam per hour with naked pipes, steam being at from 60—80 lbs. pressure per sq. in.; that is equivalent to about 0.6 lbs. per sq. ft.; pipes lagged with hair felt or other porous material lose only about $\frac{1}{10}$ of this amount.

In the table below, results of the calculation are set forward, figures relating to what has been termed uneconomical working being indicated by italics. The actual results of the calculation per 100 tons of cane are there given.

The points that stand out in strongest relief are:—

1. The heat available for working the factory depends chiefly on the fibre content of the cane, the higher the fibre not only is there more fuel but (with dry crushing) less juice to work up; this difference is so great that one factory which burns large quantities of wood or coal may be doing much more economical work than one using megass only.

B.T.U. × 1000 PER 100 TONS OF CANES.						
	A.	B.	C.	A'.	B'.	C'.
Gross B.T.U. from megass	210,384	237,990	258,018	194,161	222,622	245,428
Utilized in forming steam	115,711	130,894	141,901	107,788	122,464	134,941
Heating juice to 212° F.	18,960	18,512	18,049	21,604	21,185	20,768
Heating juice after cooling	6,320	6,171	6,016	7,201	7,062	6,923
Cleaning juice in open pans	20,482	19,515	18,547	23,977	22,283	21,235
Evaporation to 55° Balling in triple	32,341	34,083	35,562	37,729	39,659	41,263
“ “ “ quadruple	32,453	33,639	34,585	37,565	39,014	40,053
“ in pans for first sugar	27,350	21,930	16,880	29,836	23,725	17,285
“ of diluted molasses	11,950	9,447	7,072	12,862	10,127	7,885
“ “ undiluted molasses	1,232	986	739	1,330	1,084	813
Consumption in motors	8,810	8,147	7,506	9,410	8,639	7,955
Losses in steam pipes, &c.	5,785	6,544	7,095	5,389	6,123	6,747
Total for economical working	100,910	95,929	90,860	112,335	106,832	100,543
“ “ uneconomical working	131,998	124,449	118,627	148,018	138,705	130,061

2. Very excessive quantities of heat are consumed in the process of cleaning juice in open pans.

3. The re-boiling of molasses after dilution, as opposed to the process of returning them to the pan undiluted, is wasteful of fuel.

4. Weight for weight a juice of low sugar content requires less fuel than a richer one, since in the latter case more work has to be done at single effect.

5. The actual consumption of heat in the motors is small.

6. The consumption of heat with different classes of canes and different modes of treatment is very varied in its distribution.

7. With dry crushing it is only in extreme cases of low fibre, high sugar content, combined with uneconomical working, that the megass does not afford sufficient fuel for the needs of the factory.

8. With average canes, average fibre, and average sugar, very considerable dilutions can be effected without extra fuel.

9. The steam actually used in working the factory is roughly consumed thus:—

Economical Working.—Heating juice to 212° F., 18%—20%; re-heating juice after cooling, 6%—7%; evaporation in quadruple, 32%—40%; evaporation in pans for first sugar, 18%—27%; evaporation of molasses, 1%; consumption in motors, 8%—9%; losses in steam pipes, &c., 5%

Uneconomical Working.—Heating juice to 212° F., 15%—16%; re-heating juice after cooling, 5%—6%; cleaning in open pans, 15%—17%; evaporation in triple, 25%—32%; evaporation in pans for first sugar, 13%—20%; evaporation of molasses, 6%—7%; consumption in motors 6%—7%; losses in steam pipes, &c., 5%.

10. There may be a difference of 30% in the steam used between what is termed economical and uneconomical working.

The fuel value of molasses, which in certain districts, such as in Java and Hawaii, are largely used as fuel, may be touched on here. A typical refuse molasses will be of composition, say, sugar 35%; glucose 25%, organic non-sugar 13%, water 20%, ash 7%; such a molasses will have a gross thermal value of approximately 4500 B.T.U. per lb. and a net value of about 4250 B.T.U., considerably higher than for megass. Molasses are burnt either by allowing them to fall in a fine stream on megass on its way to the furnaces, or else in specially constructed furnaces, in which the molasses are atomised by means of a jet of high pressure steam.

In calculating the heat available for generating steam, the products of combustion were estimated as leaving the boiler at a temperature of 550°F.; by means of apparatus known as fuel economisers a considerable portion of this heat can be saved. A fuel economiser consists of an arrangement of tubes set in the waste flue through which the feed water passes; the latter is heated and very great economy effected. With good installations the temperature of the flue gases may be reduced as low as 350°F.; taking this temperature and assuming (as an instance of the highest economy) that only 1·5 times the theoretical minimum of air is used in combustion, the calculation of necessary losses will in this case appear as under:—

		B.T.U.
Carbon dioxide	 $\cdot 851 \times \cdot 22 (350-84)$	= 49
Oxygen	 $\cdot 258 \times \cdot 22 (350-84)$	= 15
Nitrogen	 $3\cdot 256 \times \cdot 24 (350-84)$	= 207
Associated water	 $\cdot 470 \times 1159$	= 544
Combined water	 $\cdot 294 \times 1159$	= 340
Total		1155

Compared with a loss of 1591 units under the former conditions, and leaving available for generating steam 2765 units or 70·56%, and granting a similar allowance as before for radiation losses, 65% of the gross fuel value should be utilised in generating steam; with furnaces and boilers worked under such conditions, no fuel should ever be required under any circumstances in a sugar factory other than the megass. This estimate of a utilisation in generation of steam of 65% of the gross fuel value of the megass may be taken as the highest possible in the light of present knowledge.

In Mauritius many factories have erected apparatuses known as *Sécheries* for the purpose of the utilisation of a part of the waste heat of the flue gases. A *sécherie*, *Fig. 95*, consists of a large stone or brick chamber into which the flue gases are exhausted by means of fans; it is usually about 40 feet long with an internal breadth of six or seven feet, and about 30 feet high. The green megass is delivered into the *sécherie* by the carrier *a* falling on to the upper endless belt *b*; three such belts are usually provided; from the lowest the megass falls on to the carrier *c* which conveys it to the furnaces; the carriers are formed entirely of metal and are driven at a speed of from six to eight feet per minute, the megass remaining in the *sécherie* from 15 to 20 minutes; the flue gases enter at *d* and leave through the smoke

stacks at *f*; at *g* are shown doors for cleaning up the megass which falls to the ground, and at *e* a door gives access to the interior in case of accidents. With megass containing 50% of moisture the writer has found that it will leave a *sécherie* under the best conditions with 35% of moisture, corresponding to an evaporation of half the water it originally contained. Following on what has already been written, the corresponding saving in heat units with flue gases leaving at a temperature of 550° F. is 299 for a megass with a gross thermal value of 3921 units, and the heat capable of utilisation for generation of steam is thus increased to 2689 units, compared with a previously found value of 2421 units, a gain of 11%; but this saving is effected at the following expense. Three engines are required, one to drive the fan, one to drive the carriers in the *sécherie* and one for the

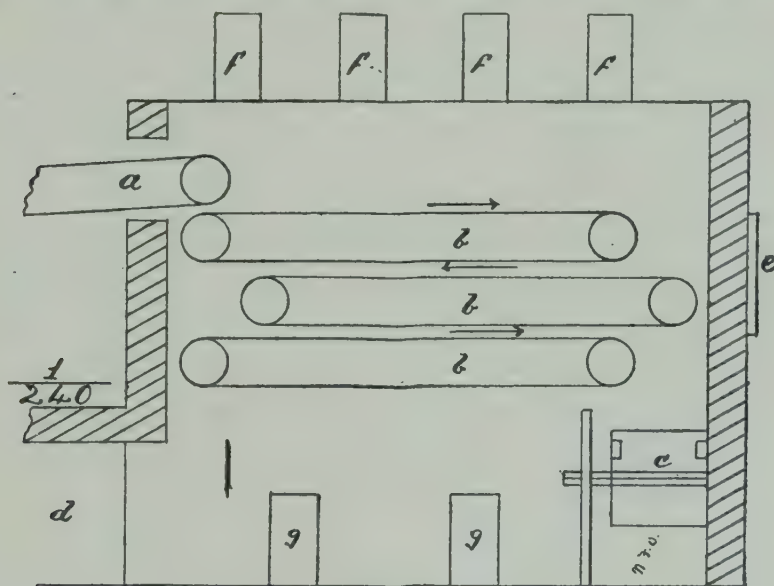


FIG. 95

cross-carrier from the *sécherie* to the furnaces. On an average as many as 15 to 20 labourers are required, chiefly for the purpose of sweeping up and carrying to the furnaces the megass which falls down. The megass in the *sécherie* is liable to ignite, and will invariably do so if the temperature of the waste gases exceeds 550° F. There is a very considerable and undeterminable mechanical loss due to the finer light and dry particles of megass being carried away; and finally, the megass in the furnaces is so fine that it falls through the furnace bars, and is liable to be swept through the flues unburnt.

The relative value of megass, wood and coal is often required, as fuel statistics are generally based on the coal value of the fuel burnt.

There is no constant fuel value for either megass or coal and any factor adopted depends on the local conditions ; coal, depending on its quality and the skill used in firing, may give from 7 to 12 lbs. of steam per lb. consumed, and megass from 1·6 to 2 lbs. per lb., depending on the like conditions. On an average from 4 to 5 tons of megass are equal to a ton of average coal. Woods, weight for weight and of the same water content, have practically identical values ; air-dried wood usually contains from 20% to 30% of water and from 3 to 3·5 tons are equal to a ton of average coal. Molasses are of very similar value to wood, the predominant factor being, of course, the water content. Cane straw contains as a rule about 10% moisture and from 2·5 to 3 tons are equal to a ton of coal. A table giving a comparison of fuel values follows :—

Fuel.	Gross B.T.U. per lb.
Welsh Steam	15,000—16,000
Pennsylvania Anthracite	15,000—16,000
Newcastle	14,000—14,500
Lancashire	14,000—14,500
Scotch	13,000—14,000
Australian	13,000—14,000
Indian	13,000—14,000
Patent Fuel	15,000—16,000
Air dried wood 25% moisture	4,500—5,000
Green Megass 50% moisture	3,500
Cane Straw 10% moisture	5,500
Molasses 25% moisture	4,500
Petroleum	16,000—17,000
Carbon	14,400

The Control of the Fuel Consumption.—The complete control of the fuel consumption of a sugar, or of any, factory, demands as two main essentials that the weight, &c., of fuel burnt and the weight of water evaporated should be known ; in addition, the thermal value of the fuel must be determined by experiment, or, as is feasible in certain cases, be calculated, and that the mean temperature of the feed water and mean boiler pressure be known. As a general rule in modern factories the weight and composition of the megass is known as a part of the factory routine, but the weight of water evaporated is not known ; any of the automatic recording devices described when dealing with the measurement of the juice may equally well be used to record the weight or volume of water pumped into the boilers. In

the absence of such contrivances for special purposes, trials of the evaporation in the boilers may be made; for a complete discussion of this subject reference should be made to Day's *Engine and Boiler Testing*.

A very useful control over the fuel consumption can be obtained by determinations of the temperature and composition of the waste flue gases as has already been indicated above. These determinations should form a regular part of the routine.

Temperature.—1. The temperature of the flue gases can be easily obtained by means of specially constructed thermometers graduated up to 700° F.; these can be obtained from dealers. The thermometer attached to a wire is suspended in the flue, the aperture through which it is passed being closed by a rubber stopper; a disused triple effect tube may conveniently be let into the flue. As the thermometer is withdrawn from the flue, the mercury rapidly falls; to prevent this the lower portion may be inserted in a brass tube and packed with asbestos; when this is done the mercury remains constant for as long as half a minute.

2. Undoubtedly the best method of determining the temperature of the flue gases, and also of the combustion chamber, is by the use of a platinum resistance or thermo-electric pyrometer. Both these instruments can be obtained supplied with automatic recording apparatus, so that a complete record of the working of the furnaces can be obtained over day and night.

If these two temperatures are known, a simple calculation gives the amount of heat carried away by the waste gases; for if T and t be the temperatures in the combustion chamber and in the flue gases, over and above the temperature of the external air, then $\frac{t}{T}$ is the proportion of heat carried away in the flue gases. In addition, there are the losses due to radiation and to unburnt fuel, but as these will be sensibly constant for any one installation, results obtained will be strictly comparative.

The apparatus required costs only about £50, and in view of the importance of fuel economy in the sugar factory, the observations suggested above should form part of the regular routine.

3. In the absence of a thermometer the temperature may be *roughly* obtained as follows: A known weight of metal,—brass, copper, iron, &c.,—is suspended in the flue until it has obtained the temperature there prevailing; it is then rapidly withdrawn, the wire snipped and

the piece of metal dropped into a known weight of water of known temperature; the rise in temperature is noted, whence the temperature of the piece of metal is obtained.

Let t_g = temperature of flue gases, t_0 = initial, and t_1 = final temperature of water, w_1 = weight, and s_1 = specific heat of metal, w_2 = weight of water, w_3 = weight, and s_3 = specific heat of vessel containing the water.

$$\text{Then } t_g = t_1 + \frac{(t_1 - t_0)(w_2 + w_3 s_3)*}{w_1 s_1}$$

4. A selection of bodies of known melting points is placed in the flue, and from their behaviour the temperature approximately estimated; the melting point in degrees Fahrenheit of bodies useful in this respect is appended. Silver nitrate, 423; tin, 455; mercuric bromide, 468; bismuth, 518; mercuric chloride, 559; sodium chlorate, 576; sodium nitrate, 591; cadmium, 608; lead, 630; potassium nitrate, 667.

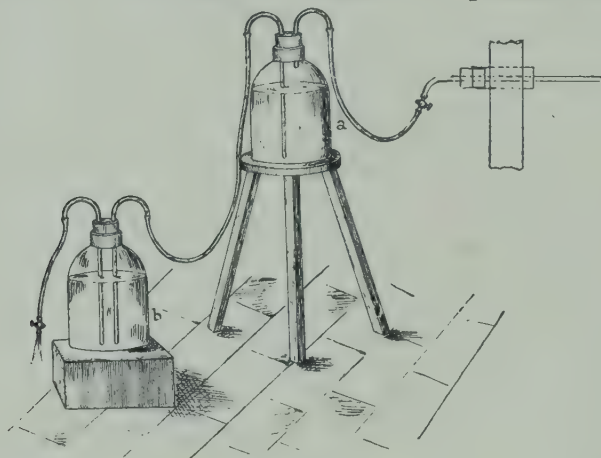


FIG. 96.

Composition of the Flue Gases.—For the analysis of the flue gases the following solutions are required:—

1. Caustic soda of density 60° Balling. For carbon dioxide.
2. Twenty-five grams pyro-gallol dissolved in 50 c.c. hot water and mixed with 100 c.c. caustic soda of density 50° Balling. For oxygen.
3. Cuprous chloride in hydrochloric acid. Dissolve 35 grams cupric chloride in 200 c.c. hydrochloric acid of specific gravity 1.20; add a quantity of copper turnings, and preserve in a stoppered bottle for 48 hours with occasional shaking; then add 120 c.c. of water. For carbon monoxide.

Collection of the Sample.—Specially designed bellows may be obtained from dealers, but the writer prefers to use the aspirator shown in Fig. 96; by means of regulating the flow of water a sample over

* Specific heat of copper .095, of brass .095, of iron .114, of glass .185, of water 1.00.

several hours' duration can be obtained. The water in bottle *a* next to the flue is covered with a layer of oil; before collecting the sample of gas the tube let into the flue should be well rinsed with the flue gases by means of alternately lowering and raising the bottle *b*.

The Analysis.—The apparatus (Orsat-Lunge) shown in *Fig. 97* is the most convenient form for analysis. The bulb *b* is filled with caustic

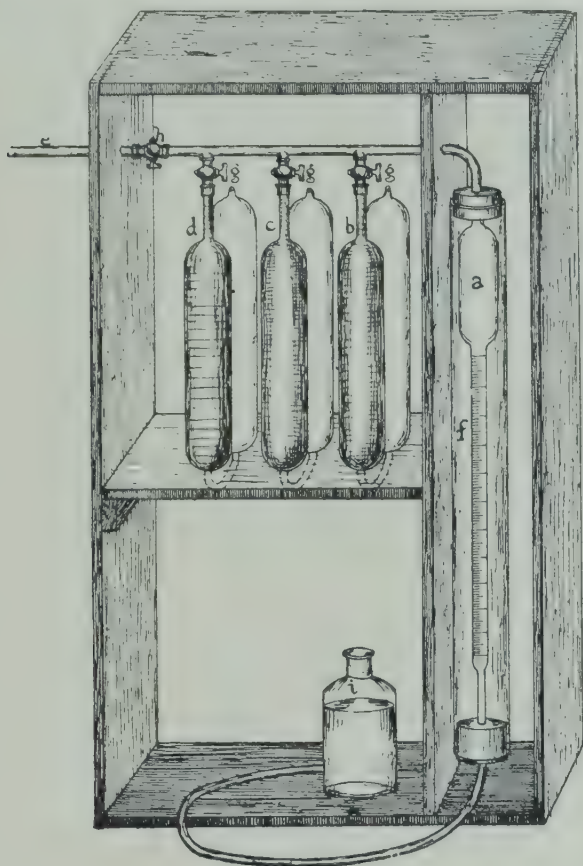


FIG. 97.

soda up to the mark on the neck, the bulbs *c* and *d* being filled in the same way with the pyro-gallol and cuprous chloride solutions. The filling is performed by first disconnecting the bulb and filling half way up by pouring in the solution; the bulb is then placed in position, the cock *g* opened, the bottle lowered, when the solution in the bulb rises and may be adjusted to the mark.

The burette *a* is to contain the measured volume of gas; it is first of all filled with water by raising the bottle *i*, the three-way cock *h* being open to the atmosphere and the cocks on the bulbs closed. The bottle containing the sample of gas is then connected with the tube *e*, the bottle *i* lowered, and the cock *g* opened to the sample bottle, the bottle *b* (*Fig. 96*) is then raised and the gas in *a* is forced into the burette;

a little more than 100 c.c. is forced in, and then by raising the bottle *i* and opening the cock *g* to the atmosphere, exactly 100 c.c. of gas may be obtained in the burette *a*, the water level in *a* and *i* being the same. The cock *g* is then closed; the bottle *i* is raised, and the cock on *b* being opened, the gas is forced into the bulb *b*, where it is allowed to remain a short time; the cock on *b* is then opened, and by lowering the bottle *i* the unabsorbed gas is drawn back into *a*, and after adjusting the water levels in *a* and *i* the volume absorbed is read off the scale. The operation is repeated to make sure that absorption is complete; the process is repeated in the other bulbs; and the nitrogen is estimated by difference.

It is a matter of common knowledge amongst those acquainted with the practical side of a sugar factory, that with certain varieties or types of cane, fuel consumption increases. In many cases this is doubtless due to decreased fibre content in the cane, resulting in an increased quantity of juice and less megass as fuel. But the writer's experience with carefully observed weighings of cane or of megass, with analyses of the latter, has demonstrated, to his satisfaction that this explanation does not always hold. Some other cause must be at work, and there appears to be considerable evidence that the thermal value of the fibre from different varieties of canes, or from canes grown under different conditions, is not the same. The writer can recall an occasion when, although the quantity and quality of the megass was not deficient, it, for no apparent reason, refused to do anything else than smoulder. One cause which may be at work is that canes grown on certain soils contain large quantities of readily fusible ash, which by preventing free circulation of air, make the megass difficult to burn.

This point is of very considerable interest, as the possession of this undesirable quality seriously detracts from the value of canes, otherwise desirable as sugar producers.

CHAPTER XX.

THE CONTROL OF THE FACTORY.

A modern factory must be conducted from the mill to the distillery as a huge chemical experiment, and efforts be made to account for every pound of sugar entering the factory; the losses should be located, and where possible corrected; where canes are purchased, not only should their weight be systematically checked, but what is as important as their actual weight, the time between cutting and milling should be strictly controlled, and perhaps, most important of all, the economic limit of mill extraction with maceration processes should be carefully determined for the conditions of the particular factory in question. There are three points in factory control each of equal importance, and neglect of one will vitiate the entire results. They are the determination of the weights of the products, their sampling, and their analysis. Where a resident chemist is employed, all these points should be under his control, and a complete and systematic record obtained; in his absence so detailed an account is not possible, but by simple analyses, such as can be performed by any member of the estates' staff, combined with attention to correct measurements and sampling, valuable and reliable data can be obtained. The points necessary to such a control are discussed below.

Weight of Canes.—The canes being the basis of all the factory calculations, the determination of their weight forms a most important item in factory control; in most modern factories served by land carriage, the canes are weighed directly on balances provided for that purpose, the only precautions necessary being a check on the exactitude of the scales and the (in general) native operator; automatic self-registering balances can be obtained, which are beyond the control of the attendant, whose functions are merely mechanical.

In factories which employ water carriage, the weight of the canes contained in the barges can be obtained by observing the displacement, but the method is not very exact, and where this mode of transport is used the weight of canes can best be deduced from the combined weight of juice and megass (see below). The weight of canes can also be inferentially determined in two ways which require

determinations of the weight of the juice and of the fibre content of the megass and canes. Let f = fibre in unit weight of cane and m = fibre in unit weight of megass; then if the weight of canes is unity the weight of megass is $\frac{f}{m}$ and of juice is $1 - \frac{f}{m}$; in general although this method is logically sound, it will be found to give too low a weight of cane when compared with actual weights reported from the balance; conversely, if the fibre in the cane be determined from analyses of the cane and also be deduced from analyses of megass and determinations of weights of canes, juice and megass, the direct analysis of the cane will in general give a lower figure than by the second method; where the direct analysis gives, say, 11% fibre, the second method may be expected to give from 11.5% to 12.0%. The differences which are almost invariably found are probably due to the impossibility of obtaining an accurate sample of cane and to the presence of undeterminable quantities of roots, trash, &c., which are weighed as cane but cannot readily be taken into account in analysis.

A second inferential method is based on the difference in composition of first and second mill juices whereby the proportion of either can be readily obtained; the method is described as for a dry crushing plant.

Let S_1 = sugar per cent. of first mill juice, S_2 of the second, and S_m of the mixed juices.

Then if the weight of the first mill juice be put equal to unity, the following equation results:—

$$\text{Second mill juice} = \frac{S_1 - S_2}{S_m - S_2}.$$

The ratio of the first and second mill juices can also be determined from analysis of the fibre content of the first and second mill megass. Let f = fibre in cane per unit weight, f_1 = fibre per unit weight first mill megass, f_2 = fibre per unit weight second mill megass; then the first mill juice per unit weight of cane is $1 - \frac{f}{f_1}$ and the second mill juice is $1 - \frac{f}{f_2} - \left(1 - \frac{f}{f_1}\right)$.

The equation

$$\frac{S_1 - S_2}{S_m - S_2} = \frac{1 - \frac{f}{f_1}}{1 - \frac{f}{f_2} - \left(1 - \frac{f}{f_1}\right)} \quad \text{results,}$$

the right hand side simplifying to $\frac{f_1 f_2 - f f_2}{f f_2 - f f_1}$.

By solving this equation, f , the fibre of the cane, is found.

This method demands for its successful use very careful analysis and sampling; it has the advantage over the method of direct analysis of the cane that the sampling of a blanket of megass is much easier than that of a train load of cane; instead of the sugar content of the juices the density as determined by the pycnometer may be substituted.

In the modern system of central factories which receive canes from several outlying stations the question of loss in weight of canes between cutting and milling is very serious, and very different results will be obtained in the factory dependent on what is considered the weight of cane; the weight at the outlying balance or the weight in the factory yard. As an example, let there be 100 tons of cane as weighed at an outlying station, containing 12% fibre, and let these canes lose by evaporation 2% before milling; the percentage of fibre will now be, calculated on a weight of 98 tons, 12.24%, and these canes will give if crushed to a fibre content of 42%, 70.91% of juice, or 68.49 tons from the 98 tons received at the factory; the “*crushing*” is then either 70.91 or 68.49 according to which weight is used; the canes if crushed fresh would have given 71.43 tons of juice.

The average loss per day in fresh cut canes, exposed in heaps of about 50 lbs., is from experiments made by the writer.

	24 hrs.	48 hrs.	72 hrs.	96 hrs.	120 hrs.
Percentage loss in weight ..	2.73	5.00	6.37	8.81	9.11
“ “ “	2.53	4.49	5.45	8.01	9.01
“ “ “ ..	3.03	3.50	5.19	7.88	8.80
“ “ “	1.59	3.62	4.63	6.26	7.64
“ “ “ ..	1.87	4.48	5.49	6.64	8.02
“ “ “	2.26	4.05	6.11	7.90	8.50
“ “ “ ..	1.41	3.05	5.20	6.09	8.52
Mean	2.19	4.03	5.49	7.37	8.57

2. *Crushing*.—The “*crushing*” is the percentage weight of juice on the canes extracted by the mills and, where the fibre content of the canes is constant, is a figure expressive of the duty of the mills, but is entirely valueless (as has been shown in the chapter on mills) when comparing results obtained with canes of different fibre content.

When the “*normal*” crushing is required in maceration processes, it can be obtained by calculation:—Let S_1 be the sugar content of first mill juice, and S_m the sugar content of the mixed juices, then

$\frac{S_m}{S_1} \times \text{weight of mixed juice}$ is the “*normal*” crushing, *i.e.*, the

weight of first mill juice which would have contained the same amount of sugar as extracted by the maceration process; this calculation is in reality quite incorrect, as the first mill juice is always of higher sugar content than the subsequently extracted juices.

3. *Weight of Megass.*—In certain factories the megass is systematically weighed as it leaves the mill on the way to the furnaces, and a very useful control over the weight of the canes is thus obtained; the automatic balances now largely used in many factories to record the weight of any material capable of being conveyed along a travelling band might well be installed for this purpose; where canes are not weighed the determination of the weight of megass affords the only direct means of arriving at the weight of the canes.

4. *Sugar in Canes.*—In mill work, as a general rule, direct analysis of the canes calculated out on the reported weight will, for reasons mentioned above, show too high a quantity of sugar entering the factory, although the actual percentage of sugar in the canes themselves may be very correctly obtained. The disturbing factors are as before the unknown quantities of trash, roots, &c., that are weighed as cane. The actual amount of sugar entering the factory is best deduced from analysis and measurements of the juice and megass; from this figure the average sugar percentage of the canes (and trash) can be calculated.

5. *Weight and Density of Juice.*—The most general method of obtaining the weight of the juice is from the record of the number of tanks filled over the day's work; it is a matter of considerable difficulty always to fill each tank to one constant level, and accordingly where accuracy is desired each tank should be provided with an overflow into the adjoining one. In many factories the juice is received cold in special measuring tanks which also serve as liming tanks, but in others the juice before measurement passes through the juice heater and is received in the clarifiers at temperatures varying from 180° F.—200° F.; in such a case the volume and also the weight of the juice can only be obtained after considerable calculation. Determine the volume of the receiving tanks when at the normal temperature and calculate their volume when at the average temperature of the heated juice; the volume of the juice when hot is thus obtained, which must now be corrected to the average temperature; the volume of a 15% solution of sugar at 84° F. being taken as

unity, the volume at 180° F. is 1·0216, at 185° F. is 1·0285, at 190° F. is 1·0303, at 195° F. is 1·0327, at 200° F. is 1·0345, at 205° F. is 1·0377. To reduce the volume of the receiving tanks to normal temperature the following formula may be used. Iron tanks:—volume cold : volume hot = 1 : 1 + (·0000185*t*); copper tanks:—volume cold : volume hot = 1 : 1 + (·0000303*t*); *t* being the difference in temperature in the Fahrenheit scale. In general, in sugar house work, one general average correction can be determined once and for all. A further correction is necessary to compensate for evaporation in the juice heater. Let B_1 = degree Balling of the raw juice, B_2 = degree Balling of the heated juice, and x = weight of water evaporated per unit weight of heated juice, then $x = \frac{B_2 - B_1}{B_1}$.

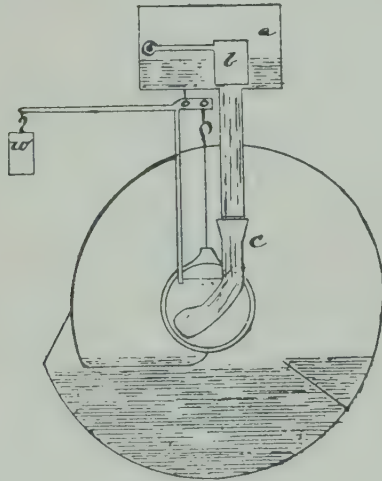


FIG. 98.

In many factories automatic devices for recording the weight or volume and density of the juice are in use; one of the simplest consists of two tanks with one common side; a short gutter into which the juice is directed is arranged with its centre over this common side; this gutter is movable, so that either end may be raised or depressed when the juice will naturally flow into that tank towards which the gutter points; in each tank there is a float which, rising as the level of the juice rises, raises the depressed end of the gutter and diverts the stream of juice to the other tank; the gutter by means of its movements works a counting apparatus.

Baldwin's apparatus for automatically weighing the juice is illustrated in *Fig. 98*; the drum *c* is divided into compartments, of which one is filling while another is emptying; this drum is

suspended from one end of a steel yard; juice flows into one compartment from the tank *a* and when balance between the drum and its contents and the counterpoise *w* is obtained, the flow of juice is automatically turned into the other compartment; as this compartment fills, the drum soon revolves and discharges the juice from the weighed compartment; when balance is nearly obtained, the flow of juice from *a* is moderated automatically; at each weighing a small sample of juice is diverted into a bottle. This apparatus is largely used in Louisiana and Hawaii.

Langen's apparatus for recording the density of the juice is shown in *Fig. 99*; the juice enters a containing vessel at *f* and overflowing

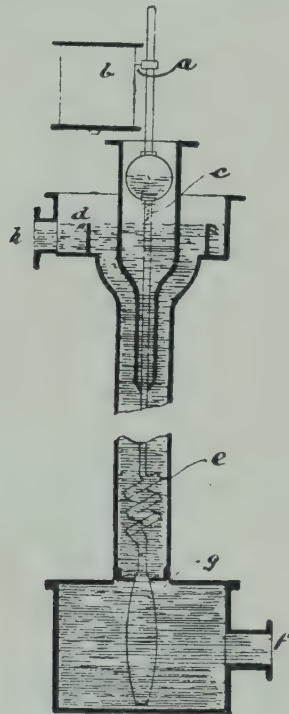


FIG. 99.

at *d* passes away at *h*; a constant level of juice is thus maintained; inside the narrow central portion of the vessel is a tube *s*, to the lower end of which is attached a rubber ball *g*; the upper portion of this tube is funnel-shaped; this inner tube is filled with water; the height of the water is dependent on the pressure on the rubber ball, the pressure being in turn dependent on the density of the juice. The level of the water is recorded by means of the float *c*, which carries a pencil *a* pressing against the cylinder *b*, which revolves by a clockwork arrangement every 24 hours; the lower portion of the inner tube is formed into a spiral at *e*, so as to ensure the juice and water being of the same temperature.

Horsin-Déon's apparatus, shown diagrammatically in *Fig. 100*, is designed to record the height of the juice in the receiving tanks. A wire or chain *a a* transmits motion from a float *b* in the tank to a drum *c* which revolves when the float rises or falls; a pinion *d* on this drum in turn drives a rack *e* which carries a pencil *f* pressing

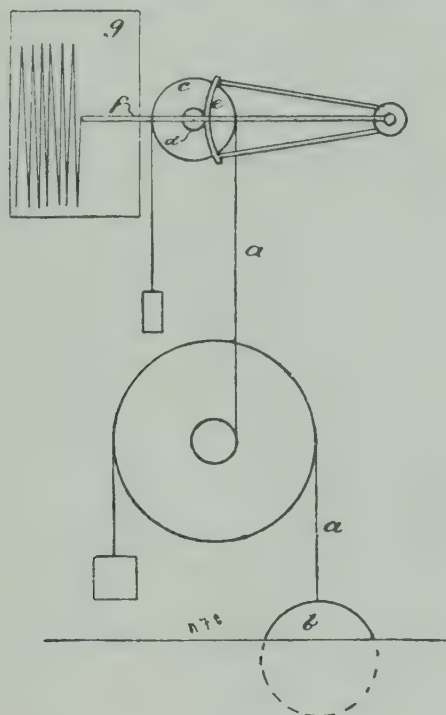


FIG. 100.

against a cylinder *g* which revolves once in every twelve hours; the height to which the pencil rises is governed by the height of the juice in the tank, and, conversely, the pencil will show if the measuring tanks have been properly emptied or whether through carelessness any "running on bottoms" has occurred.

A large number of other apparatuses, designed to automatically register the volume of the juice (chiefly invented in connection with beet diffusion factories), are in use. The main principle on which they work is as follows:—The tank having emptied, a float automatically causes the discharge valve to close and the intake valve to open; when the float reaches a certain pre-arranged level, as the tank fills the reverse action takes place; a counting apparatus, also controlled by the float, registers the number of times the tank has been filled.

6. *Weight of Maceration Water*.—The use of a meter, if cold water is used, is the best and simplest way to obtain this important quantity;

with hot water, meters are not altogether reliable, and resource must be had to the use of two tanks alternately filling and discharging, a method that with care gives very accurate results; calculation of the amount of water added from the densities of the dry crushed and mixed juices gives results which are entirely unsatisfactory; this is due to the varying composition of the juice expressed and the residual juice in megass.

7. *Dilution*.—The dilution is the amount of water which must be added to the normal juice to make its density the same as the mixed diluted juice; if B_1 be the total solids in the first mill juice, and B_2 the total solids of the mixed juice, and x the amount of water necessary to reduce unit weight of normal juice at B_1 to mixed juice at B_2 , then $x = \frac{B_1 - B_2}{B_2}$. The less the dilution the more effective has been the addition of the maceration water, the quantity of added water and the conditions of maceration remaining, of course, the same.

Weight of Syrup.—The weight of the syrup is usually obtained from volume and density determination. As the syrup will in general show fairly wide variations in density from time to time, care should be taken in sampling. The remarks made above regarding the measurement of the juice are equally applicable here. The determination of the sugar in the syrup is very important as giving a control over the entrainment losses in the evaporator. Usually, however, the volume of the syrup receiving tanks is so restricted that accurate measurement is impossible.

Weight of Masse-cuite.—In factories where the masse-cuite is received in waggons running on tram-lines, the same can easily be weighed. Where cans containing about two hundred pounds are used, these can also be readily weighed, and the importance of knowing the weight of the masse-cuite is so great that this determination should always be carried out wherever possible. With crystallisation in movement processes, a direct weighing of the masse-cuite is impossible. Methods of determining the density of the masse-cuite, whereby the weight can be calculated from the volume, are given in a subsequent chapter.

Weight of Filter Press Cake.—The amount of sugar carried away in the press cake is so small that it is barely necessary to weigh this material; sufficient accuracy can be obtained by keeping a tally of the number of presses filled and obtaining the average weight of one cake.

Weight of Molasses and After Masse-cuites.—The weight of the molasses can be roughly obtained from the difference between the sugar and the weight of the masse-cuite; allowance should of course be made for the amount of water used in the centrifugals; the weight of second and subsequent masse-cuites can be easily obtained from the volume of the tanks which receive them.

Co-efficient of Admixture of Maceration Water.—This figure is of great importance in determining the efficiency of the added water; the formula used in Java and elsewhere is:—

$$\text{Co-efficient} = \frac{\text{Sugar \% last mill juice}}{\text{Sugar \% residual juice in Megass}} \times 100.$$

The sugar % of the residual juice in megass is thus obtained: Fibre in megass = f per unit weight of megass; then juice in megass = $1 - f$, sugar % in megass = s , then sugar % residual juice in megass = $\frac{s}{1 - f}$. This figure is liable to be misinterpreted, for if small quantities of water be used in maceration, especially on megass which is imperfectly crushed, a high co-efficient of admixture will (apparently) result even if there be no admixture whatever. With megass, which has been already crushed so far as to yield no more juice without the addition of water, the simple formula above gives a valuable check; when the average fibre in the canes and final dry crushed megass is known, the weight of the dry crushed megass can be calculated, and consequently the weight of juice remaining after the dry crushing; the weight of added water being known, the sugar content of the last mill juice can be calculated for complete admixture and compared with the actually obtained results. The sugar content of the residual juice in the megass after the final dry crushing should also be obtained. In general, a factor expressing the relation between this juice and the juice expressed by the first and second mills can be obtained of sufficient accuracy to obviate the necessity of systematic analysis of the dry crushed megass.

Sampling of Juice.—The automatic weighing machines for juice, which have already been referred to, are usually constructed so as to collect from each receptacle of juice registered a small sample; in this way an exact record of the mean composition of the juice is obtained. In the absence of this apparatus an automatic sampler can easily be fitted up. Such a one is shown in *Fig. 101*; a is the main juice pipe into which is fitted a short piece of iron or copper pipe, b , of half-inch internal diameter; a perforated cork carrying the bent

piece of glass tubing *c* emerges from the end of the pipe *b* and is continued to the bottom of the bottle *d*; it is preferable to make this pipe in two portions connected by a piece of indiarubber tubing; the glass tube *e* which delivers the juice to the receptacle *f* only extends to the middle of the bottle *d*; about one inch from the bottom of the bottle is fixed a piece of fine wire gauze; the end of the tube *f* is drawn out into a fine point. The object of the bottle *d* is to act as a dashpot, and that of the gauze to keep back fine particles which might choke the end of the tube *e*. By connecting the tube *e* to a tall cylinder with a tubulure at the bottom as shown at *g*, the cylinder can be kept full with a continual flow of juice, and a hydrometer placed therein will allow of the density of the juice being continually under observation. Where the last mill juice is pumped separately this simple apparatus is invaluable in guiding the attendant at the water tanks.

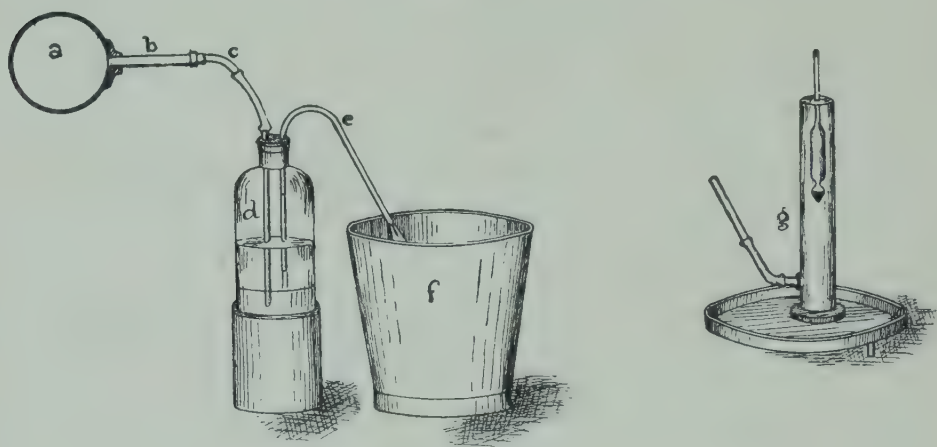


FIG. 101.

Where such apparatuses for sampling are not in use, a sample of juice should be taken from each tank filled; it is not sufficient to take an hourly sample from the mill bed. The routine followed by the writer in a certain factory was as follows. Five tanks on an average were filled hourly; as each tank filled, the foreman filled a bottle, holding approximately 100 cc., and emptied it into a larger bottle; when five such samples had been taken, the bottle was sent to the laboratory, the degree Balling ascertained and 50 cc. stored in a bottle containing one part corrosive sublimate per 5,000 of juice calculated over the day's sample. In cases where the juice is not measured cold, the same process is carried on and the polarisation of the heated juice is used in calculating the amount of sugar in the juice, making corrections for volume, &c., already referred to. In the writer's

opinion results more accurate are thus obtained than when using the polarisation of the fluid sampled at the mill bed and correcting the volume of the hot juice for evaporation; the actual polarisation of the raw juice is not of such great importance; the object of the sampling and analysis being to determine the actual amount of sugar in the juice.

Sampling of Megass.—Well crushed megass coming away in a uniform blanket is easily sampled, the only precaution necessary being to take into account the megass at the ends of the rollers, which is frequently imperfectly crushed; it is hence best to take a large sample, going right across the breadth of the mill, to mix this thoroughly and then to take a sub-sample from the large sample. Megass when sampled must be weighed for analysis at once, as it rapidly loses or absorbs moisture. Geerligs has shown that megass can be preserved for indefinite periods by means of intermittent sterilisation in sealed vessels, but this process is, perhaps, too troublesome for use except in special cases.

Sampling of Syrup.—A sample from each tank filled should be brought to the laboratory for sub-sampling, as described for the juice.

Sampling of Masse-cuites.—As each pan is struck, a sample of the masse-cuite should be allowed to fall into a suitable vessel, such as a large wide mouthed bottle; one sample from each pan strike is not sufficient, as the masse-cuite varies in composition in different parts of the pan, and a sample should be taken at the beginning, middle, and end of the strike; when the receptacle is full it should be sent to the laboratory for sub-sampling. Masse-cuites will keep for long periods, and a daily analysis is not necessary; an accurate analysis of a masse-cuite, particularly of a low one, is a process which takes considerable time; a fully accurate analysis of a carefully taken week's sample is of much more value than six inaccurate daily analyses. Low masse-cuites, boiled string proof, can be readily sampled without special precautions, as can also molasses.

Sampling of Press Cake.—A hollow cylinder with bevelled cutting edge may conveniently be used to bore out samples of press cake; but it must be remembered that the sugar content of press cakes varies largely with position.

Losses in Manufacture.—The losses that occur in manufacture are divided between the megass, filter cake, entrainment, inversion, and

final molasses, to which may be added the “undetermined losses,” a term often occurring in sugar literature. By this is meant the difference between the sugar shipped, that existing in the final molasses, press cake, &c., and that originally present in the cane. The “undetermined losses” usually include those due to entrainment and inversion, and are largely affected by errors in analysis and sampling; in fact the conventional methods of analysis when applied to low products are known to be so inexact that these “undetermined losses” may very largely be due to this cause. The best account of the sugar lost in megass is supplied by the data published by the *Ost Java Experiment Station*. The following figures, abstracted from the *International Sugar Journal*, No. 32, were obtained in the 1901 crop:—

Extraction Plant.	Sucrose extracted on 100 Sucrose in Cane.	Dilution per 100 Normal Juice.
Diffusion	94·82 ..	30·3
Triple crushing without shredders or cutters .	89·77 ..	7·4
Triple crushing with shredder	91·18 ..	12·1
Triple crushing with Ross cutter	91·85 ..	13·4
Triple crushing with two roller mill	90·01 ..	9·5
Double crushing.. .. .	87·18 ..	7·5

Results rather better than those quoted above have been obtained, but, as has been explained in a previous chapter, much depends on the fibre content of the cane. With dry double crushing the loss in megass is from 17% to 22%, and with single crushing from 25% to 30% of the sugar in the cane.

Before dealing with the losses in manufacture, the term “*available sugar*” may be explained.

The “*available sugar*” is that proportion of the sugar present in the juice which can be caused to crystallise; the factors which control this available sugar are the initial purity of the juice and the percentage of sugar in refuse—exhausted molasses.

The earlier formulæ were of the type: Available sugar = total sugar — m (glucose), m being a factor varying from unity to two. Formulæ of this type which take into consideration only one of the impurities can make no pretence to accuracy, as they would indicate a possible extraction of 100% in cases where glucose does not occur, such as in the beet sugar industry. Of later formulæ there are:—

$$1. \text{ Available sugar} = 2 (\text{sugar } \%) - \text{Balling } ^\circ.$$

This is known as the Stammer formula.

$$2. \text{ Available sugar} = \frac{\text{Sugar } \% \times 100}{\text{Purity}}.$$

In good average working $6\frac{2}{3}\%$ to $7\frac{2}{3}\%$ more sugar than indicated as available by this formula can be recovered.

$$3. \text{ Available sugar} = \text{sugar } \% - .4 (\text{Balling } ^\circ - \text{Sugar } \%).$$

This formula can also be written

$$\text{Available sugar} = \text{sugar } \% \left(1.4 - \frac{40}{\text{Purity}} \right).$$

This formula was first proposed by Winter and Carp, in Java; the writer obtained a similar formula (*International Sugar Journal*, No. 53). The formula can be most conveniently developed on the lines below.

Let there be a material containing a sugar, and b non-sugar per unit weight.

Let c non-sugar be removed, leaving $(1 - c)$ residue, containing d non-sugar per unit weight.

Then evidently $b = (1 - c) d$,

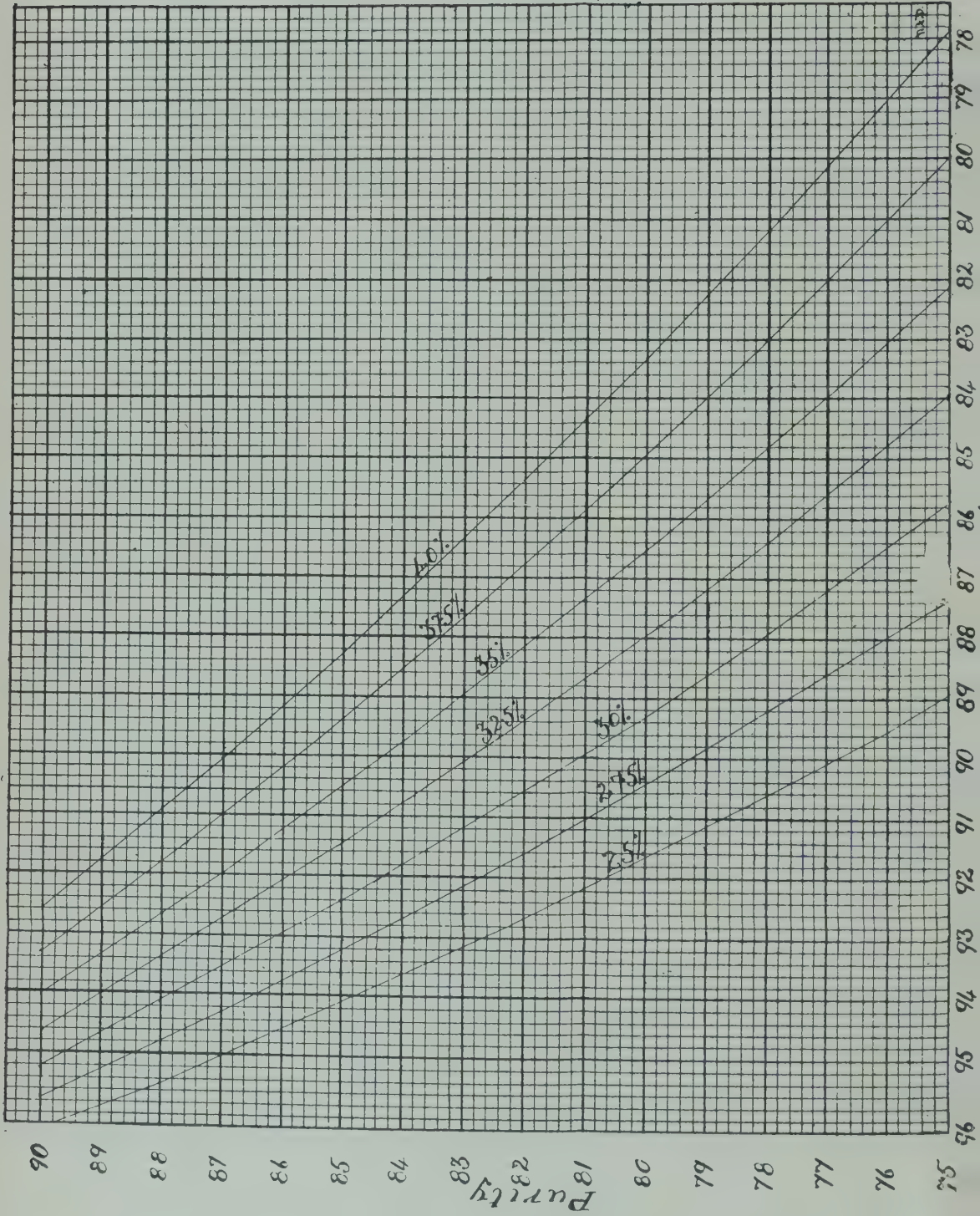
$$\text{Whence } c = 1 - \frac{b}{d}.$$

But b and d are proportional to the co-efficients of impurity of the juice and molasses respectively; and for b and d , $(1 - p)$ and $(1 - m)$ may be substituted, where p and m are the co-efficients of purity of the juice and molasses respectively. Making the substitution the formula reduces to

$$c = \frac{p - m}{p(1 - m)}.$$

This formula is capable of use in two ways; if to m be given an arbitrary value indicative of exhausted molasses, the formula represents the available sugar in the juice; with $m = 30$, the formula is almost exactly that of Winter and Carp.

But if to m be given the value found on analysis of the molasses of any factory, the formula will indicate the available sugar under the conditions of working, and the sugar actually obtained and that calculated from the formula should closely approximate; if less is obtained an error of some sort or a serious loss in working is indicated. Used in this way, the formula offers a very valuable check in factory control.



In *Fig. 102* are given curves calculated from this formula for different purities of juice and molasses, clearly showing how the recovery is controlled by these two factors.

Following on what has been said of the available sugar, the necessary and unavoidable loss in final molasses can be at once calculated; very frequently if not almost always when the sugar in the final molasses and in the press cake is determined, there still remains a large quantity of sugar unaccounted for. These unaccountable losses are due to three main causes.

1. *Errors in the conventional method of analysis* of molasses and low products, tending to make the sugar content of molasses lower than is actually the case. This point is discussed in a subsequent chapter.

2. *Entrainment Losses*.—In this term is included the sugar lost in boiling over in the pans and triple, sugar eaten and stolen by the workmen, sugar mechanically lost in handling, &c.; these losses are very hard to determine directly, and are usually estimated by difference. With careful boiling in pans and triple, very small losses occur; for beet sugar practice Baudet, Pellet, and Saillarde give the following figures:—

	Gramme sugar per 100 cc.
Condensed water in second vessel contained	·0053
„ „ third „ „	·0399
Water from air pump contained	·00951

These figures would indicate a loss in entrainment in the triple of 0·25% of the sugar in the juice.

3. *Inversion Losses*.—In modern factories, making refining crystals and working up low products by one or other of the crystallisation in movement processes, this source of loss should be entirely absent. Where low masse-cuites are stored for any length of time, inversion of cane sugar does take place to a certain extent, but the chief cause of inversion is in the process adopted for making white or yellow consumption sugars; here the juice is worked with a reaction neutral or faintly acid, and if systematic precautions are not taken to control the degree of acidity, a loss due to inversion, more or less serious, may happen. The writer has found a loss as high as 6·2% of all the sugar in the juice in boiling to first masse-cuite, and again, where the process was carefully controlled, a loss hardly to be appreciated. When working with phosphoric acid the margin of safety is so large (*vide*

Chapter XI.) that losses by inversion should not occur. Inversion losses are not absolute losses, as the loss is partly recoverable as rum in the distillery, and owing to the vagaries of the sugar market it occasionally happens that glucose is as valuable as cane sugar.

A draft scheme for a periodical return of the factory is appended. This may have to be altered to meet the requirements of any particular factory. No hard and fast rules can be laid down for the determination of yield and losses; a great deal depends on the skill and ingenuity of the chemist who should alone be responsible for this department of the factory.

The following list of apparatus and chemicals is what is absolutely essential for the laboratory of a sugar factory where sugar analysis is alone to be carried on. The prices given are only approximate.

Polariscope, 200 m.m. Schmidt and Haensch, half shadow, £30 to £40.

Three each polariscope tubes, 200 m.m. and 100 m.m., 13s.

Balance to weigh 100 grams sensitive to $\frac{1}{5}$ mgr., £10.

Rough balance to weigh 1000 grams, sensitive to $\frac{1}{10}$ gram, £2 10s. 0d.

Set of weights, 500 grams to $\frac{1}{10}$ gram, 10s.

Set of weights, 50 grams to 1 milligram, 15s.

Two sets of Balling hydrometers, 0° to 70°, graduated in $\frac{1}{10}$ degree.

Hot-air drying oven, 12 in. $\times$ 12 in. $\times$ 12 in.

Two thermometers, graduated to 240° Fahrenheit, in single degrees, 10s. each.

German-silver basin for weighing sugars, &c., 15s.

Two Swedish paraffin blast lamps, £1 each.

Six flasks, graduated 50 c.c. and 55 c.c., 1s. each.

Six flasks, graduated 100 c.c. and 110 c.c., 1s. each.

Three burettes 50 c.c., graduated to $\frac{1}{10}$ c.c., 5s. each.

Two each flasks, graduated 250 c.c., 500 c.c., 1000 c.c., 2s. each.

Two each pipettes, 10 c.c., 20 c.c., 50 c.c., 100 c.c., 1s. each.

Six hydrometer immersion tubes, 12 in. $\times$ 1 in., 1s. each.

Twelve flasks, 6 oz., 1s. each.

Six funnels, 4 in. diameter, 6d. each.

Three porcelain basins, 1000 c.c. capacity, 5s. each.

Glass and indiarubber tubing, corks, burette stands, funnel holders, spirit lamps, tripods.

A stock of the following chemicals:—

Hydrochloric acid, caustic soda, potassium, sodium tartrate, copper sulphate, sodium carbonate, basic lead acetate, neutral lead acetate, mercuric chloride, pure cane sugar.

The above list of apparatus is intended as a guide for factory requirements, where a chemist is not employed; in cases where a resident chemist is retained, and where soil and manurial analyses are carried on, a much more complete laboratory outfit must be furnished. A detailed list is not given us in such cases; the chemist employed will be aware of what is necessary.

The following notes on laboratory work are intended for the use of factories where a resident chemist is not employed.

The Balance.—A chemical balance differs in no wise except in extreme sensibility from any commercial balance; but owing to the delicacy of its construction, it must be treated with extreme care; a few minutes' use by a careless operator being sufficient to destroy its accuracy. Chemical balances are enclosed in tightly fitting cases with glass sides, access to the interior being given by a sliding door in front; the object of this is to protect the balance from damp and dust, and during weighing from draughts and other disturbing causes. As a further protection from damp, it is advisable to place in the balance a dish containing strong sulphuric acid or calcium chloride, which will absorb moisture and keep the inside of the case dry. A chemical balance consists essentially of an upright pillar, usually of brass, in which moves a second pillar which can be raised or lowered by turning a milled head screw; the top of the moving pillar is a plane surface of agate or highly polished steel; on this plane surface rests the beam which carries the pans; the beam is supported on the plane surface by a knife edge of steel or agate; the pans also hang on knife edges at the ends of the beams; when not in use the pans rest on the balance case, and by turning the milled head screw the beam and pans are raised leaving the beam free to swing; from the centre of the beam passes vertically downwards a pointer, the end of which moves over a scale, and by observing the swing of the pointer the operator can tell when the beam itself swings evenly.

When weighing on a chemical balance, determinations as to whether exact balance is obtained are not made by letting the beam come to rest, but by observing if the pointer swings through equal angles; with a properly sensitive balance it would take too long a time to let the beam come to rest.

The weights used in the laboratory are always gram decimal weights; a set will contain one 50 gram, one 20 gram, two 10 gram, one 5 gram, one 2 gram, two 1 gram weights, and so on down to .01 gram; weights smaller than this are so minute as not to be conveniently handled, and the following device is used:—The beam is divided into 100 equal parts, and a piece of wire, called a rider, weighing exactly .01 gram, is arranged to be moved at will along the beam, its effect being proportional to its distance from the fulcrum.

Steel knife edges are unsuited for a damp tropical climate, and balances with agate fittings, though more expensive, are more satisfactory. The routine of weighing out, say, an exact quantity of sugar is as follows:—

1. See that the balance is in equilibrium, when the vessel destined to contain the sugar and the counterpoise supplied by the makers are in place, and if not, adjust with small pieces of tin foil.



FIG. 103.

2. The vessel to contain the sugar being on the left-hand pan, place on the right-hand pan the weight which it is wished to obtain, and approximately the desired quantity of sugar in the containing vessel, then adjust quantity of sugar until balance is obtained. Never weigh any material directly on the pans, and never place or remove anything from the pans when the beam is free to move; the final adjustment should be made with the sliding door closed.

When weighing out large-grained sugars, an exact balance is difficult to obtain; in this case a little of the sample can be crushed and the final adjustment made with the powdered sugar.

The burette.—A burette (*Fig. 103*) is a narrow cylindrical graduated glass tube provided with a cock at one end; by opening the cock any desired volume of liquid can be run out; for laboratory purposes the

graduation is made in one-tenth of a cubic centimeter; burettes are sent out by reliable dealers very accurately calibrated and no appreciable error need be looked for. The method of use is as follows: the burette is rinsed out with the liquid to be used, filled and placed in a vertical position in the holder; the level of the contained liquid is adjusted by opening the cock until it corresponds exactly with some mark, say, 10.3; after a test has been made the level of the liquid is again noted, say, 27.6 c.c., showing that 17.3 c.c. have been used.

After use, if the burette is to be put away for any long period, the cock should be wiped dry and smeared with vaseline; if allowed to dry with the liquid remaining, the cock will probably become fixed, and efforts to remove it will possibly lead to fracture of the instrument.

The Pipette.—A pipette (*Fig. 104*) is a special form of burette designed to deliver one definite quantity of liquid. It consists of a

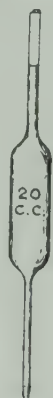


FIG. 104.

narrow piece of glass tubing, in the centre of which is blown a bulb; on the upper part of the stem is a mark. The pipette is filled by suction, the lower end being immersed below the level of the liquid and the liquid aspirated up into the burette until a little above the level of the graduation mark; the filled burette is then smartly removed from the mouth and the upper end closed with the finger; by raising the finger slowly the liquid is suffered to flow slowly out until the level of the liquid is coincident with the graduation mark, then by pressing the finger firmly down the flow is stopped and a definite quantity of liquid is contained in the pipette.

The first object of anyone working in a laboratory should be to keep all apparatus scrupulously clean; all burettes, pipettes, hydrometers, &c., after use, should be rinsed with clean water and put to drain. Cleanliness is of especial importance in a sugar laboratory.

CHAPTER XXI.

THE POLARISCOPE.

Ordinary light is supposed to be the effect on the eye of vibrations of the ether, these vibrations taking place in all directions. By certain optical devices these vibrations may be confined to one plane, and such light is called *polarised light*, the plane in which the vibrations occur being called the *plane of polarisation*. Polarised light differs from ordinary light in that when a ray passes through certain bodies, *e.g.* cane sugar, quartz and many others, the plane of polarisation is rotated; such bodies are called *optically active*, and instruments for measuring their activity are called *polariscopes* or *polarimeters*.

The chief laws under which this phenomenon occurs are:—

1. The angle through which the plane of polarisation is rotated is proportional to the length of the active material effecting polarisation.
2. The angle through which the plane of polarisation is rotated is proportional to the concentration of the solution.
3. The angle through which the plane of polarisation is rotated is dependent on the temperature, the nature of the light and of the solvent; in the case of cane sugar, the variation with temperature is not large, the nature of the light is not varied, and the solvent used is nearly always water.

The special pieces of apparatus used in polariscope analyses, apart from the instrument itself, are the polariscope tubes and the lamps. The general form of polariscope tube consists of a brass or of a glass tube, on the ends of which are fitted brass sockets; screw threads are cut on the ends; these ends are ground exactly flush and they are closed by means of glass discs; over the latter are placed rubber washers, the discs being kept in position by screwing on the brass caps. In preparing a tube for use one glass disc is placed in position, the tube held vertical and the solution under analysis poured in; air bubbles are allowed to rise when the second disc is slid on and secured by the second cap. Too great a pressure on the glass discs must be carefully avoided as the consequent distortion

may interfere with the accuracy of the reading. In a second form of tube the glass discs are held in position by a cap fitted with a bayonet catch, and in a third recent form a small cavity is made in the interior of the tube where air bubbles may collect without interfering with the reading. Glass is perhaps the better material of which to construct the tubes, and is essential when polarising the acid material resulting from Clerget's process.

Polariscope tubes are made 10 c.m., 20 c.m., 22 c.m. up to 100 c.m. in length; the standard length to which sugar observations are referred is 20 c.m.; the shorter tubes are used for very dark, and the longer for very dilute solutions; the length 22 c.m. is used to ensure an easy calculation in juice analyses.

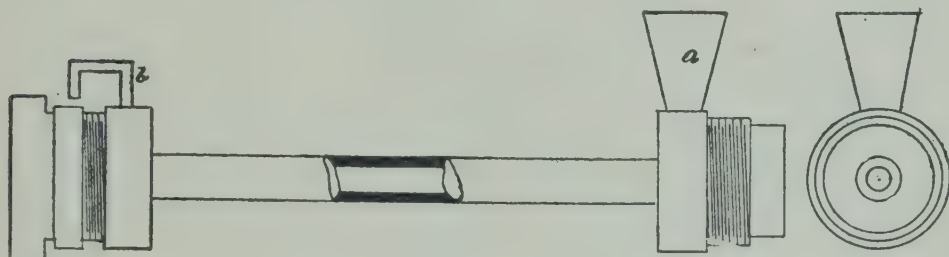


FIG. 105.

For special purposes, where a large number of analyses have to be made, Pellet's continuous observation tube is convenient; it consists of a tube (*Fig. 105*) on one end of which is a funnel *a*, a syphon overflow *b* being placed at the other end; the solution to be examined is poured into the funnel, and displaces that already there; owing to the formation of striæ, a reading cannot be obtained until the solution to be displaced is entirely removed.

All polariscopes for sugar analysis, except the earlier forms, use ordinary white light as a source of illumination; that obtained from a triplex fish tail burner is usually employed where gas is available; where spirits are used, the lamp shown in *Fig. 106* is convenient; acetylene gas as recommended by Wiley, and the Welsbach mantle as suggested by Wiechmann, give an excellent light; incandescent alcohol lamps are also very convenient.

The lamp should never be placed nearer than six inches to the polariscope, else the setting of the polariser may be damaged. Some authorities recommend that the lamp be placed in a separate room, light being admitted through a circular orifice; the writer prefers to place the instrument within a large box about four feet all ways;

one side is left open to admit the observer to the eye-piece; the lamp is placed without the box, the interior of which is painted black.

The lamps in use are provided with metal chimneys in which is fixed a concave bull's-eye lens, serving to make the rays of light parallel and give a uniform illumination to the field of vision; uniformity is not, however, easy to obtain by this means, and Lippich has modified the usual arrangement by placing the concave lens in the instrument itself and thus obtaining complete uniformity.

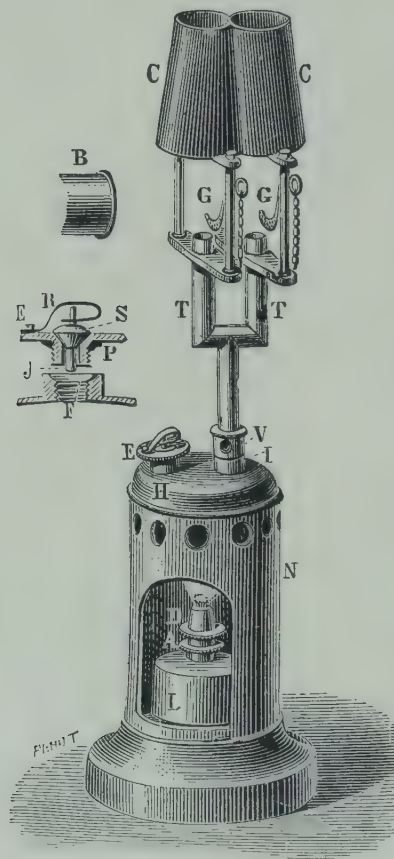


FIG. 106.

In polariscopes made for general scientific purposes the rotation of the plane of polarisation is read off a scale graduated in degrees, minutes and seconds; instruments for sugar analysis are provided with an arbitrary scale, such that when a certain weight of sugar called the *normal weight* is in a solution of volume 100 c.c., a reading of 100 is obtained with the 20 c.m. tube; when the normal weight of a substance containing sugar is dissolved, and made up to a volume of 100 c.c. and observed in a 20 c.m. tube, the observed reading gives

the actual percentage of sugar ; or, instead, any weight may be taken and the percentage of sugar obtained by calculation.

There are two normal weights in use. The one commonly used is 26.048 grams. The origin of this inconvenient number is as follows :— Ventske, the optician, whose name is connected with the transition tint instrument (see below), adopted as a standard sugar solution one of density 1.1 at 17.5° C., and marked as 100 on his scale, the rotation produced by a column of this liquid 20 c.m. long ; such a solution contains 26.048 grms. sugar per 100 c.c. There is no particular virtue in this number, and there is a strong feeling in favour of adopting a normal weight more suited for calculation, 25 or 26 grams. exactly.

The second normal weight in use, referred to sometimes as the German normal weight, is given variously as 16.19, 16.29, or 16.35 grams. It originated with Duboscq, who took as a standard of measurement the rotation produced by a plate of quartz 1 mm. thick ; this is equivalent to the rotation produced by 16.19 grams. of sugar in 100 c.c., and is marked 100 on the scale. This normal weight is used in the Laurent and in the old Duboscq instruments. The exact rotation produced by a plate of quartz 1 mm. thick is not of especial importance, as the makers state for what weight the instrument is graduated ; or it can be standardised by experiment. Polariscopes are usually graduated in Mohr's c.c. i.e. c.c. at 17.5° C. ; the Laurent instrument is for true c.c. i.e. at 4.0° C.

All forms of polariscopes depend for their working on the same principle. When the instrument is set at zero, and no optically active substance is introduced, on looking through the instrument towards a source of light, a sharply defined, easily recognisable field, called the *neutral position*, is seen. This field is destroyed by moving the scale a very little from the zero mark ; if an optically active material be introduced into the instrument, the neutral position is also destroyed. The instruments are provided with a *compensator* by means of which a rotation equal in magnitude, but opposite in sign to that due to the optically active solution, is produced, so that the neutral position again appears ; the rotation due to the adjustment of the compensator is read off a scale, and this is the same as that due to the optically active solution.

The method, by means of which polarised light is obtained, is described below. If ordinary white light passes through crystals of various bodies, such as calc spar or Iceland spar, the light suffers

what is known as double refraction, and is split up into two rays, one known as the ordinary and one as the extraordinary ray; the ray of light emerging from the prism is found to be polarised. The apparatus used in polariscopes to obtain this effect is known as a *Nicol Prism*, a section of which is shown in *Fig. 107*. A nicol prism

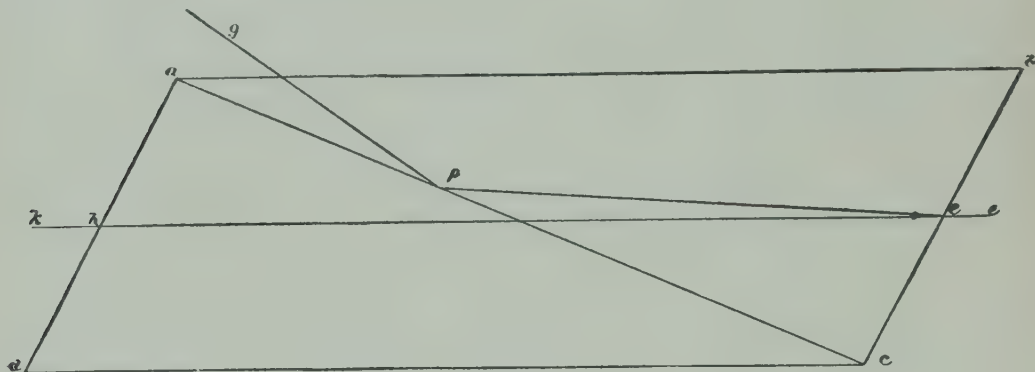


FIG. 107.

is formed out of a rhombohedral crystal of calc spar, the natural ends of which form angles of 71° and 109° ; the ends of the crystal are so ground as to form angles of 68° and 112° ; the crystal is then split diagonally at right angles to the planes of the ends and to the principal axis, *i.e.*, along *ac* *Fig. 107*; the surfaces are then polished and united with Canada balsam. Let *ee* represent a ray of light entering the prism; this ray is doubly refracted into two rays, one taking the direction *ep* and the other the direction *eh*; *ep* is the ordinary and *eh* the extraordinary ray; the ray *ep* on meeting the film of balsam *ac* is reflected in the direction *pg*, and, provided the ends of the prism have been ground to angles of 68° and 112° , will always pass out of the prism before reaching the surface *ad* and, the sides of the prism being blackened, will be totally lost. The extraordinary ray passes through the film of balsam without interference and emerges as polarised light in the direction *hk*. Now let there be a second nicol prism exactly similar to the first and the two being placed with their principal sections continuous, they may be regarded as one prism, so that the ray *hk* continues on its path unchanged and light will reach the eye of an observer; now let the second nicol be turned through a right angle; the ray *hk* in passing through the second nicol behaves as the ordinary ray and meeting the film of balsam is totally eliminated, and to the eye of an observer total darkness results. This position is known as *crossed nicols*; in all other positions some portion of the ray of light reaches the eye of an observer. Now let the second

nicol be capable of rotation, the angle through which it is rotated being read off a scale; let the zero of the scale be at crossed nicols; to the eye of an observer total darkness appears; if between the two nicols an optically active solution be introduced, on rotating the plane of polarisation α degrees, light will now reach the eye of the observer; if the second nicol be rotated through an angle $-\alpha$ degrees, the rotation due to the active solution is neutralised and total darkness again appears; the rotation of the nicol is read off the scale and this is the same as that due to the active solution. The first polariscopes due to Mitscherlich were constructed on this principle, but as the position of total darkness is not sharply defined, other devices, to be described below, are used.

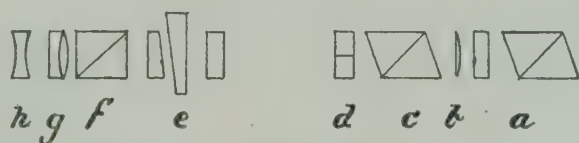


FIG. 108.

1. The *transition tint* or *colour* polariscope was originally designed by the French optician Soleil in 1848. In this polariscope the neutral position is a field of pale rose or lilac tint. This tint is obtained by eliminating from ordinary white light the yellow rays, when the rest unite to form the tint referred to. The elimination of the yellow rays is effected by the interposition in the body of the instrument of a plate of active quartz, of a certain definite thickness, one half of the plate being of dextro- and the other of laevo-rotatory variety. When this instrument is set at zero, no optically active body being present, the field of vision is uniformly of the transition tint referred to above, changing on the interposition of an optically active body to half red and half green. The neutral position is restored by means of the compensating device described afterwards. The optical parts of this instrument are shewn in *Fig. 108*, where *a* is the colour compensator, *b* a lens for obtaining parallelism of the rays of light, *c* the polarising prism, *d* the quartz plate for eliminating the yellow rays, *e* the compensator for restoring the neutral tint, *f* the analysing prism, and *hg* a telescope for focussing the field of vision. This instrument is no longer in general use.

2. The *half-shadow* instrument obtains its reference point or neutral position from a nicol prism of peculiar construction, devised originally

by Jellet and elaborated by Cornu. This device is a prism of calc-spar, *Fig. 109*, bisected in the direction of a plane passing through the shorter of the two diagonals; the sectional faces are cut down $2\frac{1}{2}^\circ$ and the two halves re-united. In this way is obtained a double nicol prism with its two principal sections at an angle of 5° to each other; if light pass through such a prism and be received by an analyser

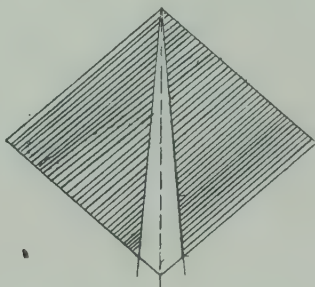


FIG. 109.

placed with its principal section perpendicular to one half of the principal section of the polariser, that half of the field appears totally dark, the other half being illuminated; by rotating the analyser through an angle of 5° , the formerly illuminated half becomes dark in its turn: between these two positions there is a point where both halves are equally in shadow. This half-shadow position forms the reference position for this instrument. The optical parts of this instrument are shewn in *Fig. 110*, and a view of the latest form as



FIG. 110.

made by Messrs. Schmidt & Haensch in *Fig. 111*.* The instrument there shewn is a double compensating instrument, mounted on a Bock stand of great rigidity, and with all the optical parts enclosed in dust proof casings.

3. The *triple field* instrument has lately been introduced and is one of great delicacy; a plan of the field is shewn in *Fig. 112*; at the

* For this and several other illustrations in this chapter the Author is indebted to Messrs. Baird & Tatlock, Optical Instrument Makers, Cross Street, Hatton Garden, London.

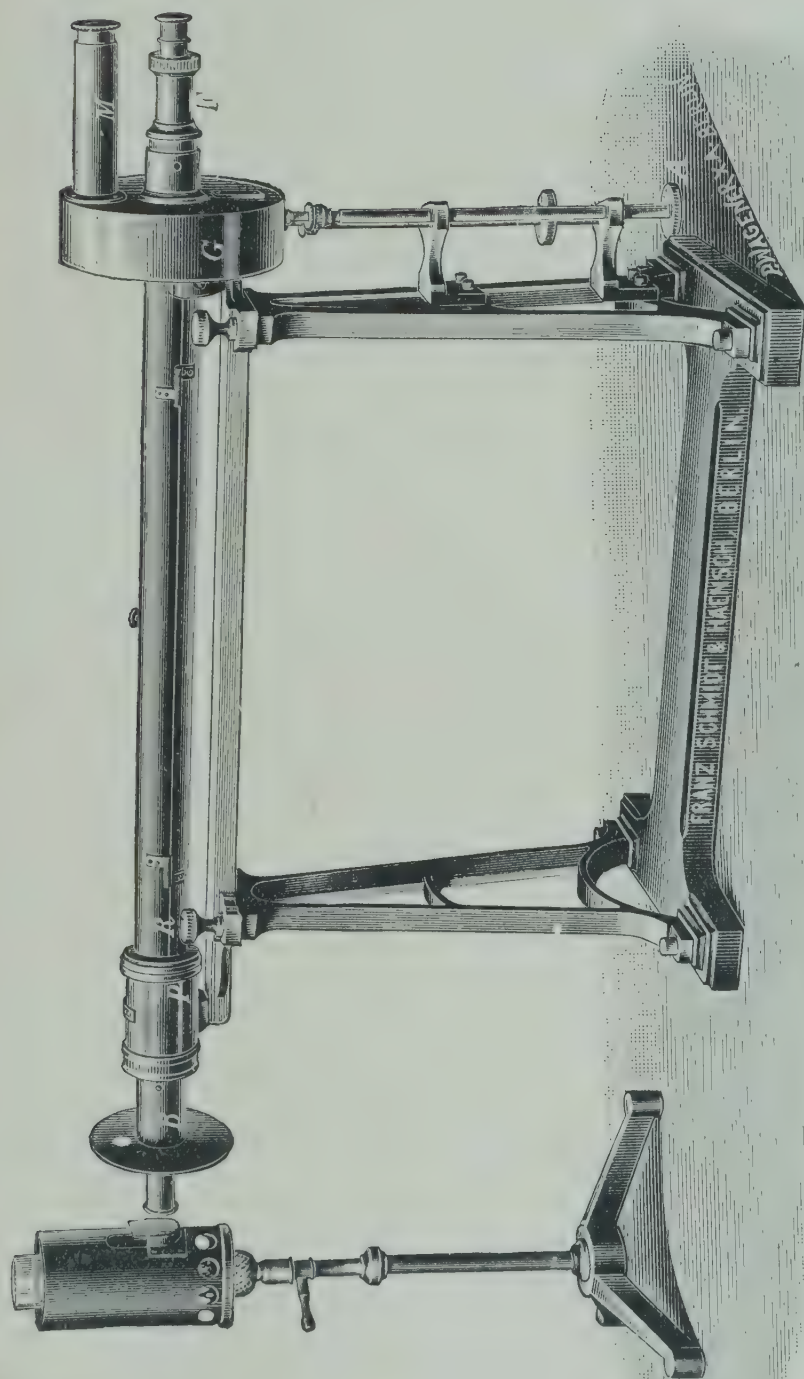


FIG. 111.

neutral position all the parts 1, 2, 3, are in uniform shade; in other positions 1 is light and 2 and 3 are dark or *vice versa*; this effect is produced by placing two small nicols in front of the polariser.

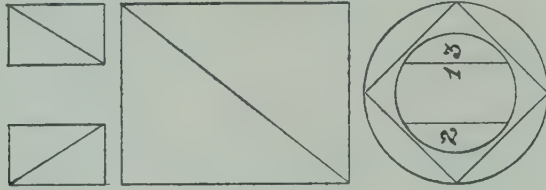


FIG. 112.

The scale of these instruments is shewn in *Fig. 113*; it consists of two parts, the lower one fixed, and the other sliding and moved simultaneously with the adjustment of the compensator. The line at which the reading is taken is that marked 0 in the upper scale: at the zero position this line is continuous with that marked 0 in the lower scale; to take a reading, the position of the zero line on the upper scale is noted with respect to the lower scale. In *Fig. 113* this is between 26 and 27. It is next observed what lines on the two scales are continuous, in this case the seventh counting from the zero: the full reading is then 26.7.



FIG. 113.

The compensator of these instruments, *e*, (*Figs. 108, 110*,) consists of a quartz plate which may be of either dextro- or laevo-rotatory material, and of two wedges of similar active material but different from that of the quartz plate. One of these wedges is fixed, the other being movable by means of a rack and pinion gear and carrying a vernier (the upper scale in *Fig. 113*). When the instrument is set at zero, the thickness of the wedges is the same as that of the quartz plate, so that the combined effect of the system is nil. By moving the position of the sliding wedge, a rotation equal in magnitude but opposite in sign to that due to any optically active material is obtained and is marked by the re-appearance of the neutral position.

The Laurent half-shadow instrument (*Figs. 114, 115 and 116*)

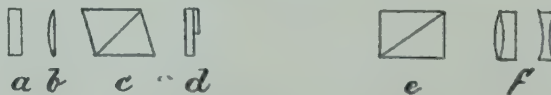


FIG. 114.

which is extensively used in France, consists of a polarising and analyzing prism arranged as above; the half-shadow reference point

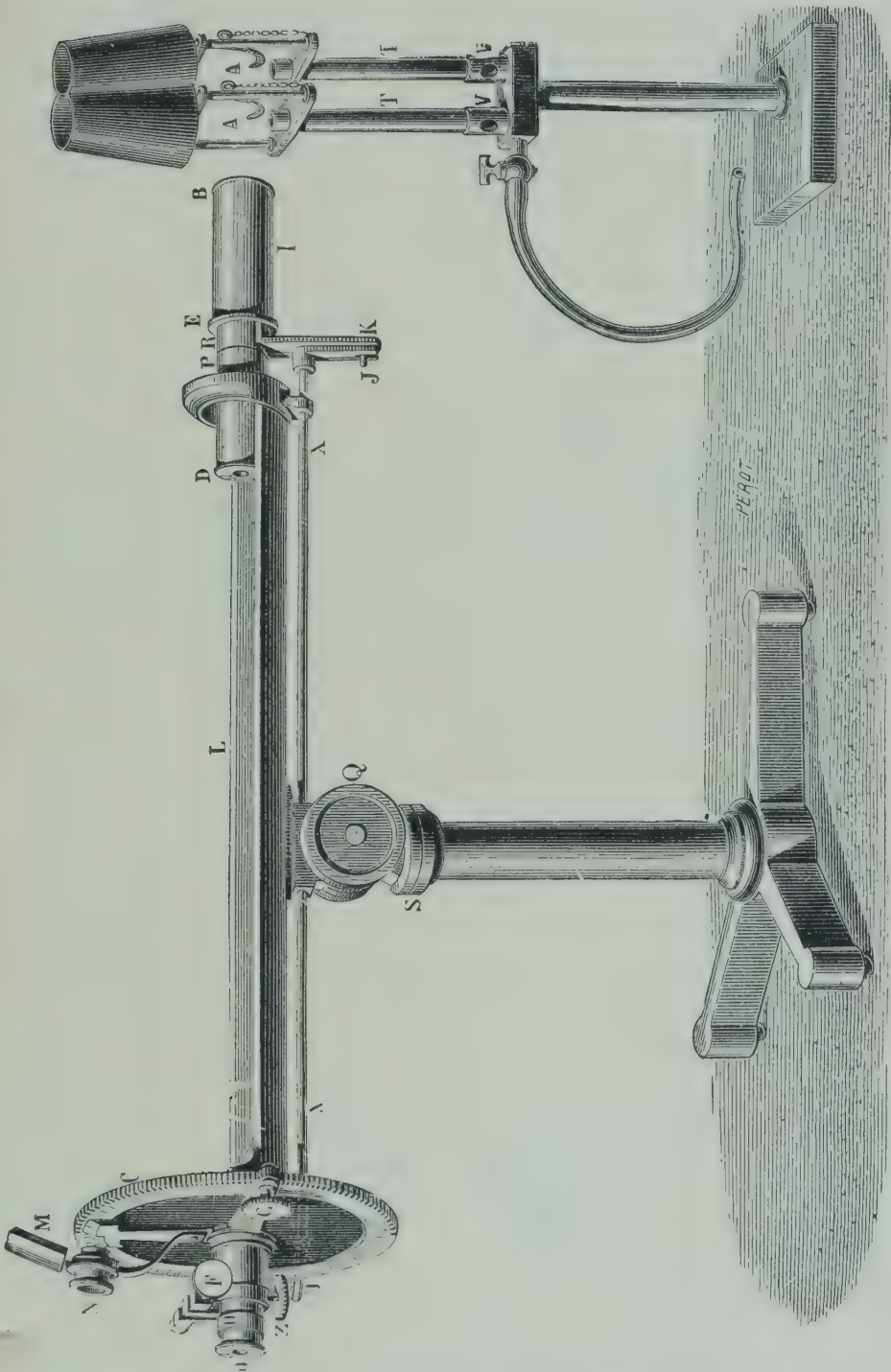


FIG. 115.

and the method of compensation are different; between the analyzer and polariser a glass disc, to one-half of which is attached a half disc of active quartz, is interposed; let the polariser be so adjusted

that the plane of polarisation of the ray of light is parallel to the axis of the plate, *i.e.*, to ab (*Fig. 117*), when in this position the two halves of the field will be equally illuminated in all positions of the analyzer; now let the polariser be inclined to ab at an angle α ; the plane of polarisation in the quartz covered half of the field f will then be rotated through an angle α , and in one-half of the field the plane

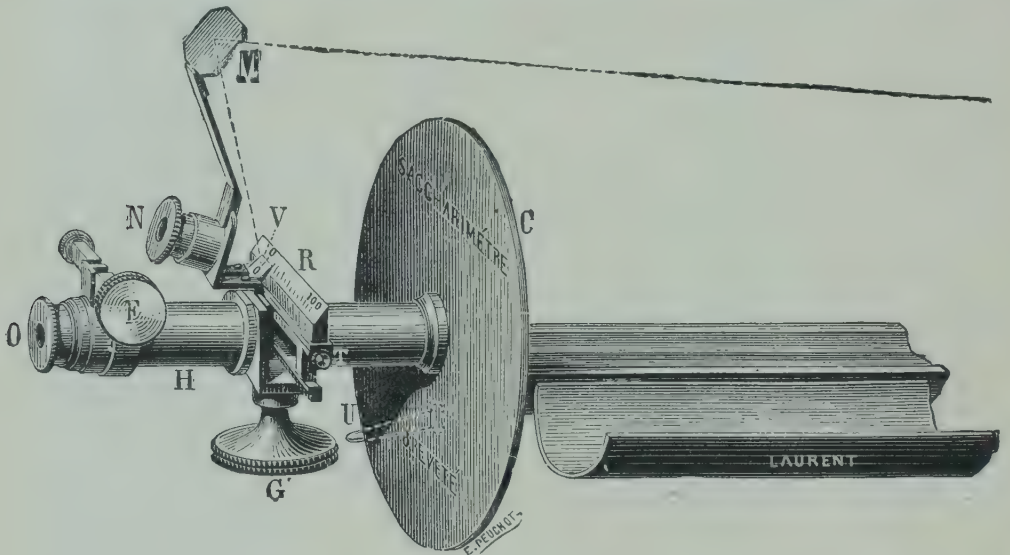


FIG. 116.

of polarisation has the direction ac' , and in the other the direction ac . Now let the analyzer be set so that its principal is in the direction dd perpendicular to ac ; then all rays in the direction ac do not pass through the analyzer, and that half of the field appears dark; similarly when the principal section of the analyzer is in the direction $d'd'$ the other half of the field is totally dark; when however the analyzer is in the position ee both halves are equally

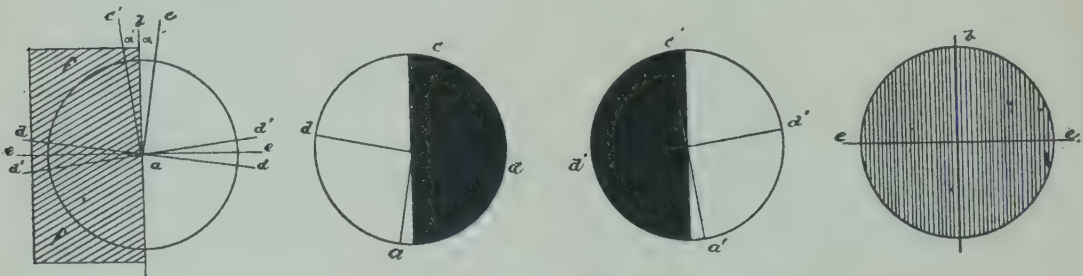


FIG. 117.

illuminated; this position marks the reference point for the instrument.

Compensation is made not by sliding wedges but by direct rotation of the analyzer as in the Mitscherlich and earlier Duboscq patterns.

The sensitiveness of this instrument depends on the magnitude of the angle a , the smaller this is the more delicate the instrument, but the less is the light that reaches the eye of the observer. The angle a can be varied and readings obtained with dark coloured solutions. In front of the polariser is placed a plate of potassium bichromate; this is removable and is intended for use with light-coloured solutions so as to make the light more monochromatic; it must not be used with dark-coloured solutions. The Laurent instrument, as usually made, is constructed to use monochromatic yellow light, and compensation is effected by rotating the analyzer; the instrument is now constructed to also use ordinary white light, in which case the sliding wedge compensation is used; both methods may be placed on one instrument, one or the other being removable at will.

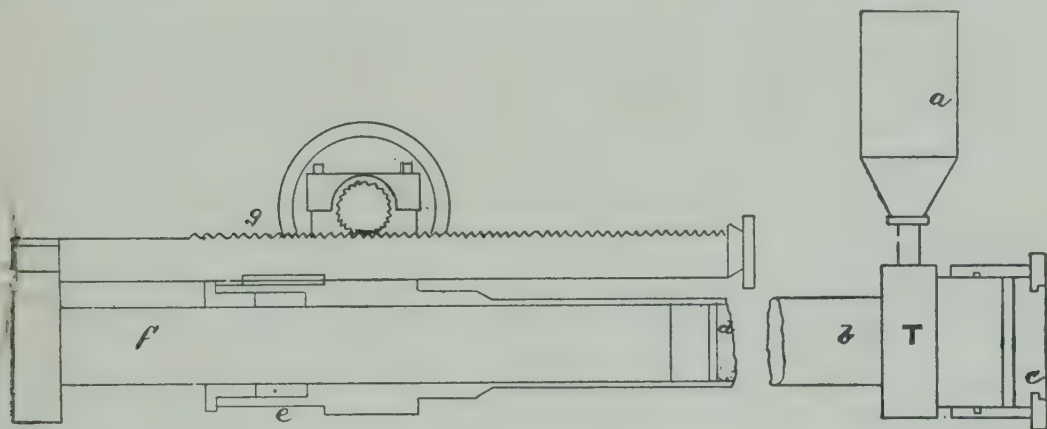


FIG. 118.

A recent improvement in polariscopes tending to eliminate accidental errors of observation, is the method of double compensation. Two sliding wedge compensators are fitted to the instrument; the milled head controlling one is coloured black and the other red; the observation is made in the usual way with the black compensator; the active solution under analysis is then removed and neutrality obtained by adjusting the red compensator; the readings on the red and black scales should be identical, practically demonstrating the accuracy of the reading, for it is very unlikely that an identical error should be made twice running, or that both compensators should possess the same error in construction.

The control of the polariscope scale is made by means of standardised quartz plates or by means of a control tube. An outline drawing of a control observation tube by Schmidt and Haensch is shown in *Fig. 118*; it consists of an outer tube *T*, in which is moved by means of

a rack and pinion gear the tube f fitting closely into T, exit of liquid between T and f being prevented by the washer e ; the tube f is closed by a glass disc at d and the tube T by a glass disc at c . The solution to be used for testing is poured into the funnel a whence it fills the tube T; the distance between d and e is regulated by the rack and pinion gear, the exact distance and also the length of the column of liquid being read off a scale carrying a vernier; the tube is conveniently filled with a solution of the normal weight of sugar in 100 cc.; with a column of liquid 20 cc. long, a reading of 100 should be obtained, and other readings should be proportional to the length of the column of liquid. A very rapid control over the scale can thus be obtained; of course the scale can also be tested by polarising different weights of pure sugar in a tube of constant length, but this, compared with the adjustable control tube, is a laborious operation.

Standardised quartz plates, the exact value of which has been carefully determined by comparison with pure sugar solutions, can be obtained from reliable makers, and serve to fix the accuracy of any particular point on the scale; they are convenient for rapid use but are inferior in general application to the control observation tube; the variation in rotation with temperature with quartz plates is considerable and is given by the formula, due to Jobin,

$\alpha^t = \alpha^0 (1 + \cdot 000146t)$ where α^0 is the rotation at 0°C. and α the rotation at $t^\circ \text{C.}$

The question of the effect of temperature on the polariscope has not been yet satisfactorily settled, the highest authorities disagreeing about the most important point, the variation of the optical activity of cane sugar with variation in temperatures. This point is quite beside the other effects of temperature which are—

1. *Increase in Length of Tube.*—The co-efficient of linear expansion of glass is of the order $\cdot 000009$ per 1°C. ; a tube exactly 20 c.ms. long at $17\cdot 5^\circ \text{C.}$, the standard European temperature, will then be at, say $27\cdot 5^\circ \text{C.}$, an average temperature in the tropics, $20\cdot 0018$ c.ms. long, and a tube of such a length would give a reading with sugar, polarising say 96° , of $96\cdot 01$. This is so small a difference as to be practically negligible.

2. *Increase in Volume of Flask.*—A flask graduated to contain 100 cc. at $17\cdot 5^\circ \text{C.}$ will contain at $27\cdot 5^\circ \text{C.}$ $100\cdot 0276$ cc., and the reading will require to be increased in this ratio; flasks for sugar analysis in

the tropics can be obtained graduated, correct at the average temperature obtaining locally, and the correction and source of error obviated.

3. If, however, a solution be made up at one temperature, say 17.5°C . and polarised at a higher temperature, the conditions are entirely altered, for the amount of sugar now contained in unit volume is less owing to the expansion of the solution ; the correction necessary can be calculated from the table of the expansion of sugar solutions given below.

4. The optical activity of quartz plates increases with a rise of temperature, and consequently with quartz wedge compensating instruments with increased temperature, a less thickness of quartz is necessary to counter-balance the rotation produced by the active material under analysis. The correction to be applied is known as Jobin's, and is given by the formula

$$P_a = P_t + (.00016t) N$$

P_a being the polariscope reading at a temperature $a^{\circ}\text{C}$., P_t that at a temperature $t^{\circ}\text{C}$., t being the difference of temperature between $t^{\circ}\text{C}$. and $a^{\circ}\text{C}$. and N being the observed polarisation in sugar grades $t^{\circ}\text{C}$. For example, according to this formula, a sugar is polarised at 15°C . and reads 96.0 ; the same sugar polarised at 25°C . will read $.00016 \times 10 \times 96 = .15$ degree lower or 95.85 .

With instruments that compensate by rotation of the analyzer this source of error is absent. Whether or no the optical activity of sugar varies with temperature, *i.e.*, whether the *same* weight of sugar contained in the *same* volume gives the same or different readings at different temperatures, is a point upon which the best authorities differ; the best method of solving the difficulty is standardisation of the polariscope against pure sugar at the temperature prevailing in the laboratory. The method adopted by J. B. Harrison in the British Guiana Government Laboratory is as under: "Each 100 cubic centimeter flask in use for sugar polarisation is verified by weighing into it 99.533 grams of recently boiled distilled water at 28°C . The exact weight of chemically pure sugar, which when made up to a bulk of 100 cubic centimeters in one of the corrected flasks at 28°C gives a polarisation reading of 100° , is ascertained by experiment for each instrument, and this weight of sugar is invariably used instead of the maker's normal weight for 17.5°C ."

* It is really immaterial whether N be the reading at $a^{\circ}\text{C}$. or $t^{\circ}\text{C}$.

CHAPTER XXII.

THE DETERMINATION OF GLUCOSE.

Solutions of glucose and of other reducing sugars, when boiled with an alkaline solution of a cupric salt, reduce the latter to the cuprous state: approximately two molecules of glucose reduce five molecules of a cupric salt, the proportion however not being a constant under varying conditions. The methods in use may be classed as *excess methods* where a definite volume of a solution of glucose is allowed to act under definite conditions on an excess of alkaline copper solution, the reduced copper being determined by one or other of the methods given below; and *direct volumetric methods* where a definite volume of an alkaline copper solution of known composition is titrated with the solution under analysis until the whole of the copper is reduced. A selection of the methods in general use is given below.

EXCESS METHODS.—Different chemists have given directions varying in detail for the reduction of the copper solution. In general, German chemists employ methods in which the mixed solutions of glucose and alkaline cupric tartrate are kept boiling for exactly two minutes. English chemists, such as Brown, Morris, and Millar, and Defren and O'Sullivan in America, keep the mixed solutions for a definite period on a bath of boiling water. In the writer's opinion, the latter method is by far the most accurate and convenient, as he finds it almost impossible to always duplicate the exact conditions of the experiment when using the German process, and the method is only exact when made under identical conditions. In the English or American method this difficulty does not occur.

The directions of Defren and O'Sullivan are given when reducing sugars only are to be determined, Meissl and Hiller being followed when cane sugar is also present. The solutions used are the same in either case, viz., 34.64 grams sulphate of copper in 500 c.c. of water (A), and 173 grams sodium potassium tartrate and 51.6 grams caustic soda in 500 c.c. of water (B).

The process may be divided into three parts, the reduction, the filtration, and the estimation of the reduced copper.

The reduction, Defren-O'Sullivan method.—Mix 15 c.c. of solution A with 15 c.c. of solution B in a 250 c.c. flask, add 50 c.c. of distilled water and place on a bath of boiling water for five minutes. Then run in 25 c.c. of the solution under analysis and allow to remain for 15 minutes exactly. The reduced copper is determined by one or other of the methods given below.

Meissl-Hiller method.—A solution containing approximately 20 grams of the mixed sugars in 100 c.c. is made up. 1, 2, 3, 4, 5, &c., c.c. of this solution are added to 5 c.c. of the mixed alkaline copper solution, boiled for two minutes and filtered. The volume of sugar solution which gives the filtrate lightest in tint is observed: 20 times this volume of sugar solution is diluted to 100 c.c., and 50 c.c. of the diluted solution are boiled for exactly two minutes with 50 c.c. of the mixed copper solution.

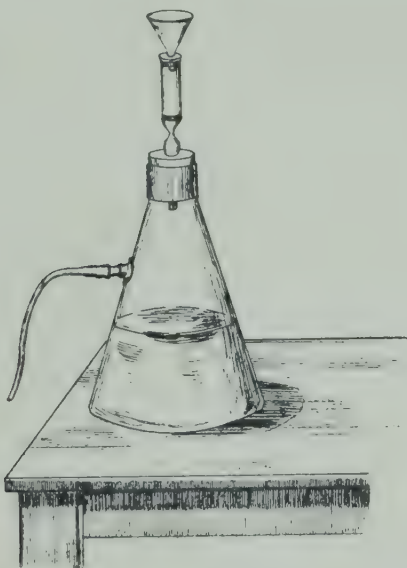


FIG. 119.

In either method the amount of sugar corresponding to the reduced copper is found from the tables below.

The Filtration.—The Filtration may be made through a Gooch crucible, a Soxhlet tube, or through paper which should not be used when either of the other methods is available. When filtering through asbestos in a Gooch or Soxhlet tube, the filtration is always done under reduced pressure. In laboratories in general a vacuum is obtained by a mercury pump or by a filter pump actuated by a fall of

water, but in sugar house laboratories where such conveniences cannot be obtained, a hand vacuum pump, such as the "Geryk," may be used with advantage.

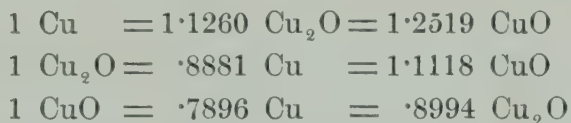
The Soxhlet tube, *Fig. 119*, consists of a glass tube about six inches long in all; the upper portion is about three inches long and half an inch in diameter, and terminates in a concave bottom to which is attached a short capillary of about $\frac{1}{32}$ bore; the lower half is about three inches long and in diameter tapers from half to $\frac{3}{16}$ in. It is prepared for use thus:—A plug of glass wool is placed on the concave bottom of the tube and above this a pad of asbestos; the plug of glass wool should be about $\frac{3}{8}$ in. deep and the asbestos about $\frac{1}{16}$; the best quality of asbestos must be used and previous to use it should be well washed, first in caustic soda, then in nitric acid, and finally in water. After the Soxhlet tube has been prepared, it is fitted into the stopper of the filter flask and filled about three parts full with water; a small funnel is then fitted on to the tube, the stem of which does not quite reach to the level of the water in the tube; the funnel is then filled with water and the pump started; as the water passes through the filter, the liquid undergoing filtration is poured into the funnel, care being taken to keep the funnel full to the brim; when all the copper oxide has been brought into the funnel, the level of liquid is maintained by hot water until all the precipitate has passed into the Soxhlet tube and is continued until the washing is complete; the copper oxide, which now forms a compact layer on the asbestos pad, is washed first with absolute alcohol and then with ether. The copper oxide is now ready for estimation by one of the methods given below. A Gooch crucible consists of an ordinary platinum or porcelain crucible, the bottom of which is perforated with a number of holes; it is prepared for use in a manner similar to that described above, except that the pad of glass wool is unnecessary. The filtration is performed under reduced pressure and the operation conducted as described above.

Filtration through paper should only be done when asbestos filtration is impossible; the paper will always retain an appreciable amount of copper which must be determined by a blank experiment, and the precipitate of copper oxide has a tendency to pass through the paper; only the best Swedish paper should be used and it must be very carefully folded.

Determination of the Copper.—The precipitated cuprous oxide may be weighed as such, as reduced copper, or cupric oxide, or it may be determined by the permanganate process or by Sidersky's method.

If weighed as cuprous oxide, the collected precipitate after washing with alcohol and ether is dried for 30 minutes at a temperature of 130°C . If the cuprous oxide has been collected in a Soxhlet tube, it may easily be converted into cupric oxide by gentle ignition, a current of air being aspirated through the tube by means of an air pump. If a Gooch crucible has been used, the precipitate may be directly ignited at a low red heat for 15 minutes. If paper has been used, the paper and precipitate are ignited in the usual way; the cuprous oxide which is in part reduced to copper is dissolved in a few drops of nitric acid, evaporated to dryness and again ignited.

The equivalent weights of copper, cuprous and cupric oxide are as under:—



The Halle experiment station recommend that the cuprous oxide be reduced to copper in a stream of hydrogen: the filtration is performed in a Soxhlet tube. In the U.S.A. Agricultural Department's laboratory the cuprous oxide is determined by electric deposition. The filtration is performed in a Gooch crucible, and it is recommended that after filtration the asbestos pad and the precipitate be removed to the vessel in which the reduction was made and the Gooch washed out with nitric acid: the copper oxide is then dissolved in dilute nitric acid, avoiding an excess, and again passed through a Gooch to remove the asbestos. The filtrate and washings are collected in a platinum basin of about 175 c.c. capacity, and after the addition of 3 to 4 c.c. of concentrated sulphuric acid are ready for deposition by an electric current. Spencer (*A Handbook for Beet Sugar Chemists*) gives the following method:—

“Where a direct current is used in lighting the sugar-house, it is the most convenient source of electricity for depositing the copper. The current must be passed through a resistance or regulator in addition to the lamp. A convenient and durable regulator is shown in (*Fig. 120*); *c* is a glass tube partly filled with water slightly acidulated with sulphuric acid; the wire *a* connects with a platinum sealed into the tube; *b* is a glass tube through which a copper wire extends and

connects with a platinum wire *e* sealed into this tube. The tube *b* may be slipped up and down, thus regulating the distance between the wires *e* and *a* and regulating the current. The twin wire *m* is separated, severed, and one end *d* connected with the platinum dish in which the copper is to be deposited and the other with the regulator *b*, thence through the acidulated water and *a* with the platinum cylinder suspended in the copper solution. Sufficient current for a large number of dishes arranged in sets of four will pass through a 16 C.P. or 32 C.P. lamp. The copper should be deposited very slowly. Usually, if the apparatus be connected when the lights are turned on in the evening, all the copper will be deposited before they are turned off in the morning." Of course this method may be used when filtering through a Soxhlet tube or through paper, adapting the directions given above to the particular circumstances.

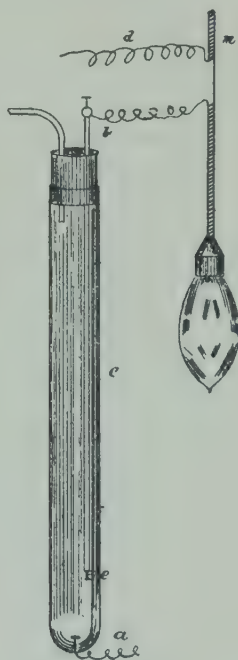


FIG. 120.

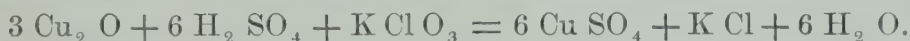
In the permanganate process the precipitated cuprous oxide is dissolved in a concentrated solution of ferric sulphate in twenty-five per cent. sulphuric acid. The ferric sulphate is reduced to ferrous sulphate in accordance with the equation—

$$5 \text{ Cu}_2\text{O} + 5 \text{ Fe}_2(\text{SO}_4)_3 + 5 \text{ H}_2\text{SO}_4 = 10 \text{ CuSO}_4 + 10 \text{ FeSO}_4 + 5 \text{ H}_2\text{O}$$

and the ferrous sulphate determined by a standard solution of potassium permanganate. This process for determining copper is of considerable age and as originally proposed the precipitated cuprous

oxide was dissolved in a hydrochloric acid solution of ferric chloride and the resulting ferrous chloride determined by a standardised solution of potassium bichromate. As undertaken in the U.S.A. Agricultural Department laboratory the filtration is carried out in a Gooch, the washed precipitate returned to the vessel in which the reduction was made, beaten up with water and dissolved in 25 to 30 c.c. of a saturated solution of ferric sulphate in 25 per cent. of sulphuric acid. The permanganate solution used contains 4.392 grams per 1000 c.c. and 1 c.c. of this solution corresponds to 5 milligrams of dextrose. Of course filtration in a Soxhlet or through paper may be employed and the copper oxide brought into solution as the experimenter thinks fit. It is also recommended that the permanganate solution be standardised by determinations of pure invert sugar. For accuracy this method may be used with tables that are constructed to give the weight of glucose corresponding to the weight of copper reduced, and when working on these lines the strength of the permanganate solution may be determined by completely reducing a known weight of copper sulphate prepared from pure electrolytic copper and thus obtaining the exact copper value of 1 c.c. of the permanganate solution. This method on the score of accuracy and expedition leaves little to be desired.

In Sidersky's method the precipitated cuprous oxide is dissolved in a measured quantity of standardised sulphuric acid to which a little potassium chlorate has been added. The reaction proceeds as follows:



The excess of sulphuric acid is then titrated with standard alkali, or an excess of standard alkali may be added and titrated back with standard sulphuric acid: in the presence of free ammonia the solution is blue changing to green when all the ammonia is saturated. It is advised that half normal ammonia be employed. The amphotère in this method appears to the writer's eye inconveniently large, the change from blue to green not being at all sharp. The ammonia and sulphuric acid solutions should be standardised against each other, using 2 c.c. of a concentrated solution of copper sulphate as an indicator.

DIRECT VOLUMETRIC METHODS.—In these methods a fixed quantity of the alkaline copper tartrate solution of the composition given above is titrated with the solution under analysis until all the copper is precipitated as copper oxide. As this method is the one usually

employed in tropical sugar factories by unskilled workers, it is described in full detail the remarks and directions applying *mutates mutandis* to the other volumetric processes given. The mixed solution of copper sulphate and alkaline tartrate is known as Fehling's solution: this is a deep blue solution which on boiling with glucose throws down a precipitate of red oxide of copper (cuprous oxide), the solution at the same time becoming lighter and eventually colourless, provided that a pure solution of glucose be used. With cane juices, &c., the solution after precipitation of all the copper is yellow in colour. Fehling's solution, as sold in the shops, is twice as concentrated as the solution obtained by mixing equal bulks of the copper sulphate and the alkaline tartrate solutions, and 10 c.c. of the one or 20 c.c. of the other will be completely precipitated by approximately .05 gram of glucose. As Fehling's solution when mixed is apt to decompose, it should be standardised before use, and even if its components are kept separately it should still be standardised, as copper sulphate crystals are difficult to obtain pure. The standardisation is performed by titrating the Fehling's solution with a solution of invert sugar of known composition until all the copper is precipitated; in subsequent analyses the conditions of the standardisation must be strictly adhered to. The manipulation of a determination, whether standardisation or analysis, is as follows:—

10 c.c. of Fehling's solution as found in the druggist's shops or 20 c.c. prepared as described above are placed in a small flask or large test tube and about 50 c.c. of water added: the exact quantity is immaterial so long as a fixed measure is adhered to. The whole is brought to the boil and the glucose solution added in quantities of 1 c.c. from a burette to the boiling Fehling's solution until the addition of 1 c.c. causes the final discharge of the blue colour. This preliminary experiment gives the amount of glucose solution required to the nearest c.c. If the number of c.c. taken differs materially from that of the solution used when standardising, it should be diluted until of approximately the same strength. A second portion of Fehling's solution is now diluted and boiled and a quantity of glucose solution added, just a little less than that which the preliminary experiment has shown necessary, and the whole boiled for exactly two minutes; the glucose solution is then added drop by drop to the still boiling mixture until all the copper is reduced. Owing to the yellow colour of cane juices, etc., in alkaline solution, the disappearance of the blue colour is not sharp, and the critical

point of the operation is determined as follows:—A solution of copper and potassium ferrocyanide in acetic acid solution give an intense brown coloration. A drop of the nearly completely reduced Fehling's solution is removed in a *Wiley* or *Knorr* filtering tube and placed on a porcelain tile; to this is added a drop of potassium ferrocyanide solution and a drop of acetic acid; the presence of copper in solution is shown by a red coloration. This test is made for every drop of glucose solution added, after the blue colour has become indistinct.

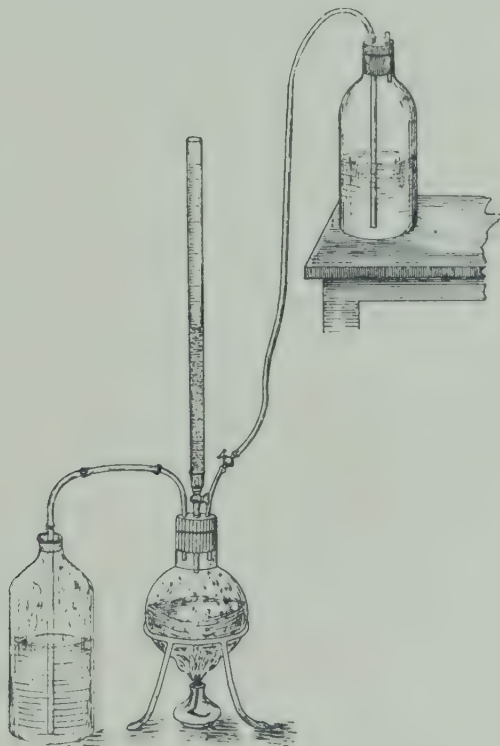


FIG. 121.

Wiley's filter tube consists of a glass rod with a flange formed by softening one end and pressing on a wooden block; over this flange is tied a piece of linen and an asbestos film is formed on this by suction. Knorr modified this by sealing in the end of a glass rod a perforated platinum disc. On placing one of the tubes in the turbid liquid and applying suction, a little of the liquid is filtered through the asbestos free of copper oxide; after using each time the tube should be washed out.

A convenient strength for the glucose solution will be found to be one such that 20 c.c. contain approximately .05 gram glucose.

Pavy's Method.—In Pavy's modification of Fehling's method, ammonia is added with the object of keeping in solution the cuprous oxide. The solution is prepared by adding to 120 c.c. of Fehling's solution (10 c.c. = 0.5 gram glucose) 300 c.c. of ammonia 0.880, and making up to 1 litre; 50 c.c. of this solution are reduced by 0.025 gram of glucose. The determination is made as follows:—The apparatus (*Fig. 121*), consists of a flask holding about 150 c.c., into the neck of which is fitted a rubber stopper carrying three tubes, one of which communicates with a reservoir of ammonia by a rubber tube carrying a screw clamp; a second communicates with a burette containing the glucose solution, the flow of which is controlled with a screw clamp; the third serves to carry away and condense under water the escaping fumes of ammonia: the whole apparatus is supported by suitable holders; 50 c.c. of Pavy's solution are placed in the flask and boiled, ammonia being allowed to drip slowly into the flask. As soon as the air is expelled, indicated by the almost complete absorption of the escaping bubbles, the glucose solution is slowly added and continued until the blue colour is discharged; the last few drops should be allowed to flow very slowly. The addition of the ammonia must be continued throughout the experiment, and as, notwithstanding the partial expulsion of the air on boiling the reduced copper reoxidises, the experiment should be made as expeditiously as compatible with accuracy. The remarks above in describing Fehling's method as regards standardisation, conditions of experiment, &c., are equally applicable here.

Peska's Method.—Peska's modification of Pavy's method consists in covering the copper solution with a layer of pure paraffin and conducting the experiment at a temperature of 80° C, the copper solution not being allowed to boil. The solution employed by him is 6.9 grams pure copper sulphate and 160 c.c. of 25% ammonia in 500 c.c., mixed immediately before use with an equal volume of 34.5 grams Rochelle salt and 10 grams of caustic soda, also in 500 c.c.; 100 c.c. of the mixed re-agent are reduced by 80.2 milligrams of dextrose in 1% solution, or by 84.0 milligrams of invert sugar in 1% solution.

In the determination of "glucose" the chief points to be remembered are that dextrose and levulose, of which the "glucose" of the sugar cane is composed, have different reducing factors, and that the amount of copper reduced depends on the time of boiling, the composition of

the solution, and on the amount of sugar present; hence when using tables the exact directions of the authors must be followed; in sugar-house work the analyst has to deal with a varying mixture of dextrose and levulose so that attempts to obtain extreme accuracy by gravimetric processes are necessarily spurious, and the simpler volumetric methods may be employed. In the control of the distillery, where the glucose and not the cane sugar is the important factor, volumetric methods are not of sufficient accuracy, and excess methods should be employed; as, after inversion, the great proportion of the glucose is invert sugar, tables for the determination of this body may be used without serious error.

Complex mixtures of sugars do not enter into the routine of the tropical sugar-house analyst; but the following table giving the behaviour of sugars after treatment with invertase and acids will be useful:—

		Dextrose.	Levulose.	Lactose.	Maltose.	Saccharose.	Gallisin.
Original	Reducing power.	100	93·8	67·8	62	..	45·6
After treatment with invertase }		100	93·8	67·8	62	102·0	45·6
After inversion with acid .. }		100	93·8	97·7	105·3	102·0	..
Original	[α] _D	+52·7	-98·8	+55·8	+139·2	+66·5	+84
After treatment with invertase }		+52·7	-98·8	+55·8	+139·2	-24·3	+84
After inversion with acid .. }		+52·7	-98·8	+71·0	+55	-24·3	..

Defren's table given immediately below refers to glucose proper, or dextrose, and not to invert sugar or to the indefinite mixture of dextrose and levulose occurring in sugar-house work and referred to as glucose. If invert sugar is to be determined, the amount can be found by adding 3·3% to the corresponding quantity of dextrose, and 6·6% in the case of levulose.

DEFREN'S TABLE FOR THE DETERMINATION OF DEXTROSE.

Milligrams of Cupric Oxide.	Milligrams of Dextrose.	Milligrams of Cupric Oxide.	Milligrams of Dextrose.	Milligrams of Cupric Oxide.	Milligrams of Dextrose.	Milligrams of Cupric Oxide.	Milligrams of Dextrose.
30	13.2	66	29.1	102	45.3	138	61.3
31	13.7	67	29.5	103	45.7	139	61.8
32	14.1	68	30.0	104	46.2	140	62.2
33	14.6	69	30.4	105	46.6	141	62.7
34	15.0	70	30.9	106	47.0	142	63.1
35	15.4	71	31.3	107	47.5	143	63.6
36	15.9	72	31.8	108	48.0	144	64.0
37	16.3	73	32.2	109	48.4	145	64.5
38	16.8	74	32.6	110	48.9	146	64.9
39	17.2	75	33.1	111	49.3	147	65.4
40	17.6	76	33.5	112	49.8	148	65.8
41	18.1	77	34.0	113	50.2	149	66.3
42	18.5	78	34.4	114	50.7	150	66.8
43	19.0	79	34.9	115	51.1	151	67.3
44	19.4	80	35.4	116	51.6	152	67.7
45	19.9	81	35.9	117	52.0	153	68.3
46	20.3	82	36.3	118	52.4	154	68.7
47	20.7	83	36.8	119	52.9	155	69.2
48	21.2	84	37.2	120	53.3	156	69.6
49	21.6	85	37.7	121	53.8	157	70.0
50	22.1	86	38.1	122	54.2	158	70.5
51	22.5	87	38.5	123	54.7	159	70.9
52	23.0	88	39.0	124	55.1	160	71.3
53	23.4	89	39.4	125	55.6	161	71.8
54	23.8	90	39.9	126	56.0	162	72.3
55	24.2	91	40.3	127	56.5	163	72.7
56	24.7	92	40.8	128	56.9	164	73.2
57	25.1	93	41.2	129	57.3	165	73.6
58	25.5	94	41.7	130	57.8	166	74.1
59	26.0	95	42.1	131	58.2	167	74.5
60	26.4	96	42.5	132	58.7	168	74.9
61	26.9	97	43.0	133	59.1	169	75.4
62	27.3	98	43.4	134	59.6	170	75.8
63	27.8	99	43.9	135	60.0	171	76.3
64	28.2	100	44.4	136	60.5	172	76.8
65	28.7	101	44.8	137	60.9	173	77.3

DEFREN'S TABLE FOR THE DETERMINATION OF DEXTROSE.

(Continued.)

Milligrams of Cupric Oxide.	Milligrams of Dextrose.	Milligrams of Cupric Oxide.	Milligrams of Dextrose.	Milligrams of Cupric Oxide.	Milligrams of Dextrose.	Milligrams of Cupric Oxide.	Milligrams of Dextrose.
174	77.7	211	94.4	248	111.3	285	128.3
175	78.2	212	94.9	249	111.8	286	128.8
176	78.6	213	95.3	250	112.3	287	129.3
177	79.1	214	95.8	251	112.7	288	129.7
178	79.5	215	96.3	252	113.2	289	130.2
179	80.0	216	96.7	253	113.7	290	130.6
180	80.4	217	97.2	254	114.1	291	131.1
181	80.8	218	97.6	255	114.6	292	131.5
182	81.3	219	98.1	256	115.0	293	132.0
183	81.8	220	98.6	257	115.5	294	132.5
184	82.2	221	99.0	258	116.0	295	133.0
185	82.7	222	99.5	259	116.4	296	133.4
186	83.1	223	99.9	260	116.9	297	133.9
187	83.5	224	100.4	261	117.3	298	134.3
188	84.0	225	100.9	262	117.8	299	134.8
189	84.4	226	101.3	263	118.3	300	135.3
190	84.9	227	101.8	264	118.7	301	135.7
191	85.4	228	102.2	265	119.2	302	136.2
192	85.9	229	102.7	266	119.6	303	136.6
193	86.3	230	103.1	267	120.1	304	137.1
194	86.8	231	103.6	268	120.6	305	137.6
195	87.2	232	104.0	269	121.0	306	138.0
196	87.7	233	104.5	270	121.4	307	138.5
197	88.1	234	105.0	271	121.9	308	138.9
198	88.6	235	105.4	272	122.4	309	139.4
199	89.0	236	105.9	273	122.8	310	139.9
200	89.5	237	106.3	274	123.3	311	140.3
201	89.9	238	106.8	275	123.7	312	140.8
202	90.4	239	107.2	276	124.2	313	141.2
203	90.8	240	107.7	277	124.6	314	141.7
204	91.3	241	108.1	278	125.1	315	142.2
205	91.7	242	108.6	279	125.6	316	142.6
206	92.2	243	109.0	280	126.1	317	143.1
207	92.6	244	109.5	281	126.5	318	143.6
208	93.1	245	109.9	282	127.0	319	144.0
209	93.5	246	110.4	283	127.4	320	144.5
210	94.0	247	110.9	284	127.9		

MEISSE & HILLER'S TABLE FOR INVERT SUGAR IN MATERIALS
CONTAINING MORE THAN ONE PER CENT.

Ratio of Sucrose to Invert Sugar = R : I.	Approximate absolute weight of Invert Sugar = Z.						
	200 Mgrs.	175 Mgrs.	150 Mgrs.	125 Mgrs.	100 Mgrs.	75 Mgrs.	50 Mgrs.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
0 : 100	56.4	55.4	54.5	53.8	53.2	53.0	53.0
10 : 90	56.3	55.3	54.4	53.8	53.2	52.9	52.9
20 : 80	56.2	55.2	54.3	53.7	53.2	52.7	52.7
30 : 70	56.1	55.1	54.2	53.7	53.2	52.6	52.6
40 : 60	55.9	55.0	54.1	53.6	53.1	52.5	52.4
50 : 50	55.7	54.9	54.0	53.5	53.1	52.3	52.2
60 : 40	55.6	54.7	53.8	53.2	52.8	52.1	51.9
70 : 30	55.5	54.5	53.5	52.9	52.5	51.9	51.6
80 : 20	55.4	54.3	53.3	52.7	52.2	51.7	51.3
90 : 10	54.6	53.6	53.1	52.6	52.1	51.6	51.2
91 : 9	54.1	53.6	52.6	52.1	51.6	51.2	50.7
92 : 8	53.6	53.1	52.1	51.6	51.2	50.7	50.3
93 : 7	53.6	53.1	52.1	51.2	50.7	50.3	49.8
94 : 6	53.6	52.6	51.6	50.7	50.3	49.8	48.9
95 : 5	52.6	52.1	51.2	50.3	49.4	48.9	48.5
96 : 4	52.1	51.2	50.7	49.8	48.9	47.7	46.9
97 : 3	50.7	50.3	49.8	48.9	47.7	46.2	45.1
98 : 2	49.9	48.9	48.5	47.3	45.8	43.3	40.0
99 : 1	47.7	47.7	46.5	45.1	43.3	41.2	48.1

Let C = weight of copper obtained, P = polarisation of the sample, W = weight of material in the 50 c.c. used in the analysis, F = the factor obtained from the table for the conversion of copper into invert sugar, $\frac{C}{2}$ = approximate absolute weight of invert sugar = Z, $\frac{Z \times 100}{W}$ = approximate percentage of invert sugar = Y, $\frac{100 P}{P \times Y} = R$ relative number for sucrose, $100 - R = I$ relative number for invert sugar = W, $\frac{CF}{W}$ = percentage of invert sugar.

The factor F used in the calculation is obtained from where the vertical column Z meets the horizontal column R : 1. Example:—Approximate weight of invert sugar = 129 mgrms., and R : I = 96.3 : 4.2. The nearest values in the table to these are Z = 125, R : I = 96 : 4; where these meet we find the value 49.8 = F, which is used in the calculation.

CHAPTER XXIII.

THE ANALYSIS OF SUGAR HOUSE PRODUCTS.

In the following chapter the principal methods of analysis of sugar house products are described both from the view of the chemist and of the non-technical man in cases where the necessary control work of a sugar factory is performed by unskilled assistance.

ANALYSIS OF THE CANE.

The analysis of the cane is seldom directly made in sugar house work, the composition of the cane being deduced in general from the analyses of the juice and megass; direct analyses of the cane are, however, necessary for experimental work and sometimes as a valuable control upon the results obtained in the factory.

1. *Inferential Methods.*—The canes under analysis are cut into strips and passed through a small hand mill; in general, splitting the cane into quarters will give strips which can be easily milled; the expressed juice is collected, weighed and polarised to obtain the sugar content; by assuming a fibre content for the cane, the sugar percentage of the cane can be calculated from the percentage of sugar in the juice. This method is open to the following objections which entirely destroy its accuracy; the fibre content of the cane is not even approximately uniform but varies between the limits of 8% and 16%; the composition of the juice in a cane is not constant, that first expressed being always richer than that obtained on subsequent crushings.

In Java the sugar percentage of the canes is regularly deduced in mill work from the sugar percentage of the first mill juice, being taken as .85 of the latter; this factor corresponds roughly to a fibre content of 12%.

2. *Complete Methods.*—To obtain an accurate account of the sugar in the cane a complete extraction must be made. Milling or diffusion methods may be employed; in the former, the sample of cane after weighing is cut into strips and crushed in a small hand mill; the expressed juice is collected and its weight determined; in actual

practice the writer has not found it feasible to obtain the weight of juice directly, as a considerable portion squirts out over the sides of the mill and a portion is also retained on the rollers; the weight of juice obtained can be found, however, by weighing the megass which can be easily and completely collected; no appreciable error due to loss or absorption of moisture by the megass is to be feared as the whole process of crushing a sample of cane (say, one kilo), collecting and weighing the megass, can be performed in from two to three minutes. The megass is analysed as described below, and the sugar content of the cane found as the result of the analysis of the juice and megass. Instead of using a mill to break up the cane, machines specially constructed for laboratory use and designed to pulp vegetable substances can be employed; such machines consist of a series of circular saws revolving at a very high velocity which reduce the cane to a state of pulp. A portion of the pulped cane is weighed out, placed in a basin and boiled gently for half an hour, with the addition of a little basic lead acetate; after cooling, the basin and its contents are weighed, and the weight of water obtained, the extract is polarised and after a large allowance for fibre and density of the extract, as in the example below, the sugar content of the cane is obtained.

	Grams.
Weight basin	50
„ „ and pulped cane.. . . .	80.5
„ pulped cane	30.5
„ basin, pulped cane and water	143.7
„ of extract and fibre	93.7
Polarisation of extract	14.0

Assuming that the cane contains 12% fibre, the weight of the fibre is 3.7 grams, and the density of the extract may, without unreasonable error, be taken as 1.015. There are, therefore, 90.0 grams of extract of density 1.015 or 88.6 c.c., which contain $88.6 \times 14.0 \times .026048 = 3.231$ grams of sugar; the percentage of sugar in the cane is then 10.59%.

The addition of the lead acetate early in the process is to prevent any inversion on boiling; if any alkali such as lime or soda be used, gummy bodies active to the polariscope are rendered soluble.

This method of analysis can be used without the pulper; the cane can be easily split into thin strips with a sharp stout knife with practically no loss of juice.

When analysing cane or canes, it is of essential importance to remember that the cane is not of uniform composition, and a sample must represent the whole length of the cane. When making systematic control analyses of cane the writer has pursued the following method: A factory was grinding sixteen car loads per hour; from every car load one cane was selected; when sixteen canes were thus obtained, the top sixteenth was cut from the first, the second sixteenth from the second, and so on; each piece of cane was then split longitudinally with a sharp knife, first into halves, then one half into quarters and finally into eighths; from the sixteen canes a sample weighing on an average 200-300 grams was obtained representing each portion of the cane; proceeding systematically on these lines as many as 100 canes can easily be analysed in a day of eight hours. The glucose in canes is obtained by analysis of the extract and the fibre as described below for megass.

ANALYSIS OF MEGASS.

For technical control determinations of the water, fibre and sugar are necessary.

Water.—The determination of the water in megass so as to obtain figures representative of the working of the mills is a problem which is not so easily solved as at first sight appears. The chief difficulty lies in obtaining a sample of a bulk convenient for analysis and at the same time representative of the many tons of megass made in a day. In the writer's experience the very smallest sample for the actual analysis that can be obtained is one of about 50 grams weight, obtained as a sub-sample from one of several kilograms taken across the whole width of the rollers. Megass is a material that is exceptionally retentive of moisture, and when dried under atmospheric pressure at the temperature of boiling water is not completely dried in less than 24 to 48 hours. The time taken for drying depends very largely on the way the material is arranged in the oven; the drying is quicker the greater the surface exposed. The writer has found shallow tin trays about 4-5 inches square, and half an inch deep very suitable; such trays easily hold 50 grams of megass exposing a large area; gauze baskets or linen bags do not give such good results as regards time occupied in drying. When the drying is carried out at atmospheric pressure, a temperature in the oven of 240°F. is necessary, if the megass is to be dried within a reasonable time; megass placed in a layer in a shallow

tray will be completely dried in from five to six hours at this temperature. A high temperature is not, however, suitable for drying vegetable products, as certain of the constituents, particularly levulose, are oxidised and increase in weight. Ovens, called hot air ovens, intended to be heated over a direct flame, can be obtained from dealers in apparatus; a convenient size for sugar house work is one of 12 inches internal measure all ways; shelves are placed in the oven every two inches, so that it may contain as many as 24 trays each six inches square; such ovens are made double-walled except on the side where the door is placed; on the bottom of the lower outer wall is a circular aperture about three inches in diameter. The oven is placed directly over the lamp, the heated air from the lamp passing upwards between the two walls and completely bathing the inner chamber; an ordinary paraffin stove forms a very convenient burner for this oven. Whenever possible, however, a vacuum oven should be installed in a sugar house laboratory, and one can usually be made at very small expense on the estate. The one due to Carr, and described in Wiley's *Agricultural Analysis*, vol. III., consists of a brass tube from six to nine inches in diameter and from 12 to 15 inches long; one end is permanently closed by a plate brazed on; on the other end is placed a washer of soft material against which is pressed a plate, the external pressure being sufficient to make an air tight joint; apertures for the introduction of a thermometer and of an inert gas are provided, as well as means for connecting the apparatus to a vacuum pump.* The oven is heated by means of a gas flame extending the whole length of the oven.

The vacuum in a sugar house can best be obtained from the last body of the multiple effect evaporator; a half-inch pipe is led from the vapour space of the last body to the oven; on this pipe, conveniently close to the oven, is fitted a small cock so that the oven may be opened and closed without affecting the evaporator; on the oven itself is placed a second cock, so that after connection with the multiple has been cut off the vacuum may be broken and the oven easily opened. Such an oven is conveniently made double walled, so that it may be heated with exhaust steam from the factory.

Fibre.—What is returned as the fibre in the cane or megass is the material insoluble in water; the method used by the writer consists of washing in linen bags about 50 grams of megass until all soluble matter is removed. The hot water from the second and third

* These ovens can now be obtained from dealers in apparatus.

bodies of a triple effect forms a very convenient source of hot water ; the bags of megass securely closed are left in a stream of this water for two hours ; then placed in cold water to cool, squeezed with the hand, emptied into a shallow tray and dried in the oven to constant weight. The weight of the residue calculated out to 100 is taken as the percentage of fibre in the cane or megass.

Sugar.—About 50 grams of megass are boiled with about 250 c.c. of water after addition of lead acetate for 15 minutes. The extract after cooling and weighing is polarised and the calculation made as described for cane. In the analysis of economically exhausted megass a very small reading of only about 2° or less is obtained with the 20 c.m. tube, and hence the result can only be looked on as approximate. To obtain a larger reading, a polariscope taking a 60 c.m. tube should be employed ; such a polariscope only costs about £5 more than one to take a 20 c.m. tube, and in view of the importance of this analysis it would be preferable to instal the larger model.

The extraction of the sugar and determination of the fibre can also be performed in a Soxhlet extraction apparatus ; the largest size procurable, and capable of holding 50 grams of megass, should be used ; the solvent employed may be water or more conveniently aqueous alcohol ; a few drops of lead acetate placed in the solvent will prevent any inversion ; 50 grams of megass can be extracted with less than 100 c.c. of solvent ; after complete extraction the extract is made up to 100 c.c., filtered if necessary and polarised. This method saves the calculation due to presence of fibre in the extract, and gives a reasonably large reading even in the 20 c.m. tube ; the analysis, however, takes a considerable time to make.

The determination of the fibre in cane or megass can also be made with considerable accuracy in accordance with the example below.

A sample of megass gives on analysis the following results:—water, 48·50% ; sugar, 4·82% ; the purity of the last mill juice being 78·62.

The percentage of total solids in solution in the megass is, then,

$$\frac{4\cdot82 \times 100}{78\cdot62} = 6\cdot13\%.$$
 The percentage of fibre is, then, the difference between 100 and the sum of the percentages of the water and solids in solution ; in this case 45·37%.

ANALYSIS OF THE JUICE.

As an analysis of the juice is made in all factories, whether a chemist is employed or not, the operations are described in detail.

Density.—The density of cane juice or of any liquid is the ratio of the weight of a volume of the liquid compared with the weight of an equal volume of water which is put equal to unity. In actual technical control the density of the juice is determined by means of a hydrometer; the method of weighing in a specific gravity bottle or pycnometer is too lengthy for general use and is reserved for special experiments. A hydrometer consists of a glass or metal instrument of the shape shown in *Fig. 122*; on the hydrometer being

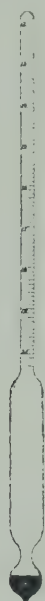


FIG. 122.



FIG. 123.

immersed in the liquid it will sink to a certain point dependent on the density of the liquid; the point where the level of the liquid cuts the stem of the hydrometer gives on the scale the density of the liquid; it will be noticed that the liquid will rise as much as one-eighth of an inch up the stem of the hydrometer as shown in *Fig. 123*. The lower level of the liquid is the point at which the reading is taken. Hydrometers are graduated to show the density of the liquid directly or in terms of some arbitrary scale. The scales most frequently met with are the Beaumé and the Brix or Balling; the Beaumé scale has nothing to recommend it and should be entirely abandoned; the Brix or Balling scale is constructed specially for use with sugar, and is so calculated that the

degree Brix or Balling at once indicates the percentage of sugar when the hydrometer is immersed in a solution of pure sugar and water. The standard temperature at which technical observations are taken in Europe is 17.5°C . or 63.5°F .; instruments may be used, graduated at this temperature which will give the degree Balling, or the percentage of sugar, and by reference to a table the specific gravity or density compared with water at this temperature. The temperature in a tropical sugar house laboratory is always much higher and if instruments graduated for European use are employed a correction must be used. To avoid the inconvenience of the correction, instruments graduated at the average prevailing temperature to give correct readings compared with water at 17.5°C . or with water at the prevailing temperature can be obtained; it is perhaps better to compare the specific gravity of cane juices with water at 60°F ., as at this temperature a gallon of water weighs exactly 10 pounds. The general formula connecting the degree Balling or the percentage of sugar with specific gravity at 17.5°C . is: specific gravity $= \frac{B^{\circ}}{259.7 - B^{\circ}}$; at a temperature of 84°F . compared with water at 60°F . the formula is: specific gravity $= \frac{B^{\circ}}{272 - B^{\circ}}$.

Cane juice, however, contains many other bodies than cane sugar which affect the specific gravity of the solution in quite a different way to the latter; in a cane juice, then, the degree Balling does not indicate the percentage of sugar; it indicates, however, what is called the *apparent total solids*, all the solids in solution being considered as affecting the density as cane sugar.

The actual practice of taking the degree Balling or total solids is as follows:—If juice from the mill bed is being analysed, the sample is poured into a cylinder about 12 inches high by 3 inches diameter; this cylinder is provided at the bottom with a tubulure, in which is fitted a perforated cork carrying a bent piece of glass tubing, which may be closed by a piece of indiarubber tubing and a clip; such cylinders with draw-off cocks ground in may be obtained at a small price from dealers in apparatus. The sample is allowed to stand for about five minutes when the air bubbles will have risen to the surface and the dirt have sunk to the bottom; a clear, negotiable sample can then be drawn off into a second cylinder, the hydrometer inserted, sunk so as to wet the stem, allowed to come to rest and the degree Balling noted; the temperature is taken at the moment of observation; for each degree Fahrenheit above or below that at which

the hydrometer is graduated $\cdot 035$ of a degree Balling should be added or subtracted. The preservation of samples for analysis has already been referred to in Chapter XX.

The apparatus for taking the density of the juices may conveniently be arranged as shown in *Fig. 124*; it is a shallow tray two feet square lined with lead, from which leads a pipe to carry off waste; a tap for a water supply is arranged over the tray by means of which a current of water is always available for cleaning apparatus and for cooling hot juices; over the tray is placed a shelf in which are pierced

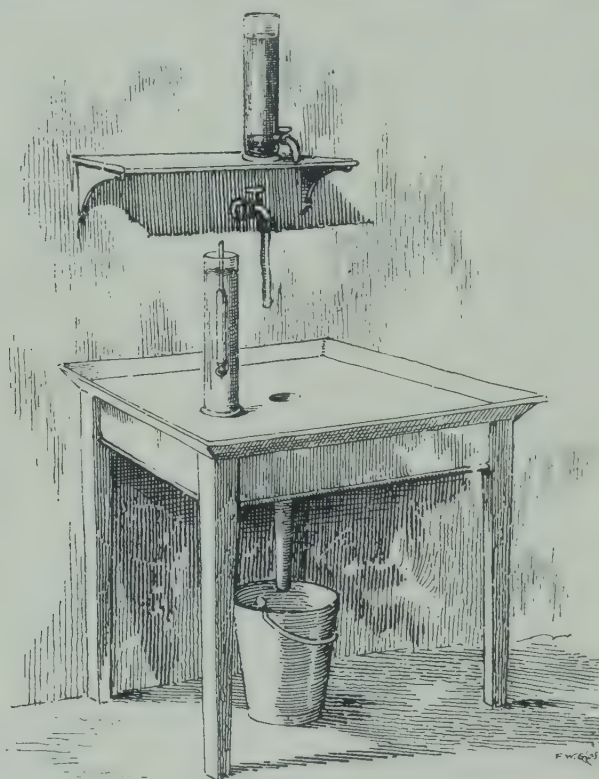


FIG. 124.

a number of holes by means of which apparatus may be hung downwards to drain; the shelf also serves as a stand for cylinders in which the juice is settled. By the use of an arrangement like this, the density determinations and sampling can be done without spilling juice about the laboratory and the whole apparatus easily kept sweet and clean.

True Total Solids.—The *true total solids*, as distinguished from the *apparent total solids*, can only be determined by drying a definite weight or volume of the juice. Cane juice cannot be dried completely at the temperature of boiling water at atmospheric pressure

except by exposure for lengthy periods, and the drying should be conducted under reduced pressure in a vacuum oven, such as the one already described. To further accelerate the drying, the method of increasing the exposed area by absorbing the cane juice by an indifferent material is largely used; this method was first proposed by Wiley & Broadbent for use with honey, clean dry sand being the material suggested; pumice stone is recommended for use by Carr & Sanborn, and strips of filter paper crimped into a coil by Josse; whichever method is used, a dish is partly filled with the material, the liquid poured evenly into the dish so as to be uniformly absorbed; the weight of liquid added is determined by weighing and dried to constant weight preferably in a vacuum oven.

Purity.—The purity of a juice is the percentage of sugar to the total solids and is obtained by calculations. When the total solids are deduced from the degree Balling, the term *apparent* purity is used as distinguished from the *true* purity obtained when the total solids are determined by drying.

Sugar.—The determination of the sugar in the juice is carried out in actual practice as follows:—A flask with two graduation marks, one at 100 c.c. and the other at 110 c.c., is filled to the 100 c.c. mark with the sample of juice under analysis; six or seven cubic centimetres of a solution of basic lead acetate of density 1.25 are then added and the whole made up to 110 c.c. by the addition of water. The flask and contents are then violently shaken and filtered through a dry filter into a narrow cylinder; those sold by dealers as hydrometer immersion tubes, about six inches in height and one inch in diameter, serve admirably; the funnel which holds the filter paper may conveniently be stemless and rest on the rim of the receiving glass so as to prevent evaporation. After sufficient of the juice has been filtered, a 20 cm. polariscope tube is filled with the filtrate which must be perfectly clear and bright, the polariscope tube closed, placed in the trough of the polariscope and the reading observed. If N be the normal weight for the polariscope and R be the reading, the sugar in the juice as grams per 100 c.c. is $\frac{N \times R \times 1.1}{100}$; the pounds per gallon, as it is general to express results in English factories, are one tenth of this result; the percentage of sugar is obtained by dividing the grams per 100 c.c. by the specific gravity. This routine can, of course, be varied; the normal weight of cane juice may be weighed out, a sufficiency of lead acetate added, the whole made up

to 100 c.c., filtered and polarised; the reading in the polariscope will now give directly the percentage of sugar in the juice. Spencer's pipette is a convenient instrument for obtaining the normal weight of a cane juice without the use of the balance; the upper stem of an ordinary pipette is graduated with numbers corresponding to tenths of a degree Balling; when the pipette is filled to one of these marks the weight of liquid delivered is the normal weight for juice of that particular degree Balling; for polariscopes which have a normal weight of 26.048 grams these pipettes deliver twice, and for those whose normal weight is 16.19 grams three times, the normal weight of juice. The polariscope reading (after making up to 100 c.c.) divided by two or three as the case may be, gives the percentage of sugar in the juice.

The above process of analysis, though generally used, is open to two sources of error; the bodies precipitated by the lead acetate occupy a certain volume so that the sugar is contained in less than 100 c.c.; this source of error tends to load the factory with more sugar than actually enters, and, secondly, other optically active bodies may be present. The first source of error can be eliminated by Schleibler's method of double polarisation:—The juice is first polarised as above; 100 c.c. of juice are diluted after clarification with lead acetate to 200 c.c. and polarised; if a be the first reading and b the second reading, the true reading is given by the expression $a - 2.2(a - 2b)$.

In Sach's method of correcting for the volume of the lead precipitate, the precipitate from 100 c.c. of juice is washed by decantation till free from sugar and transferred to a 100 c.c. flask; the normal weight of a pure sugar of known polarisation is then dissolved in the same flask, the volume made up to 100 c.c. and the solution polarised; from the reading the volume of the lead precipitate can be at once calculated. The error due to the volume of the precipitate is very small and decreases as the purity of the juice increases; in the analysis of molasses, however, the error becomes more noticeable.

The two chief optically active bodies other than cane sugar present in cane juice are dextrose and levulose, summed up together under the term glucose. The glucose in cane juice has been stated to be both dextro and lævo-rotatory, and also to be inactive. Winter in Java has shown that the glucose in cane juice consists of varying proportions of dextrose and levulose, generally in such amounts that the combined effect is only very slightly appreciable and may entirely vanish; when extreme accuracy is desired the sugar may be deter-

mined by Clerget's method, or as glucose after inversion; these methods are described below.

Glucose.—In most works that deal with the analysis of cane juice, the process recommended is as follows:—A quantity of the filtered cane juice which has been prepared for polarisation, say 20 c.c., is removed in a pipette, mixed with an equal bulk of a 10% solution of sulphate or carbonate of soda, filtered, and the glucose determined by one or other of the methods already given. It was shown by Gill that basic lead acetate and levulose interact to form an insoluble lead levulosate, so that when levulose is present in the juice this body is partly removed before analysis; lead levulosate is not formed in acid solution and Gill recommended the acidification of the solution with sulphurous acid before filtration; a more convenient proceeding is to clarify with neutral lead acetate, made by adding acetic acid to basic lead acetate, to faint acid reaction. The routine followed by the writer is as follows:—Ten c.c. of cane juice are placed in a 50 c.c. flask, 2 c.c. of neutral lead acetate added, the flask shaken and then 10 c.c. of a 5% solution of sulphate of soda added, and the whole made up to 50 c.c., filtered, and the glucose determined in the filtrate; when using the ordinary Fehling process, the quantity of diluted juice required to precipitate the copper should be between 15 c.c. and 20 c.c.; with very pure juices it may be necessary to dilute a larger quantity of cane juice to 50 c.c., and with impure juices a less quantity.

Ash.—It is customary for chemists to distinguish between the sulphated ash and the normal ash; the complete incineration of sugary bodies is difficult and is found to be materially assisted by previous carbonation with strong sulphuric acid; in this case the salts in the ash are present as sulphates, and it is found that on an average the weight is increased 10%, and in tabulating results this allowance is made. The details of the process are as under:—10 c.c. of the juice are measured by a pipette into a platinum dish, or any convenient quantity may be weighed out, evaporated to dryness, a few drops of strong sulphuric acid added, and ignited at a low red heat, just visible in daylight until a white ash remains.

The carbonated ash referred to by some writers is obtained by a similar process, the ash being evolved as carbonate by the addition of 2 c.c. of a solution of 25 grams of benzoic acid in 100 c.c. of alcohol.

The normal ash is that obtained by ignition of the evaporated juice without the addition of any agent.

Determinations of the ash of the juice do not enter into the usual routine of the sugar house chemist; the quantity of the ash and its composition is, however, a point of much importance in the agricultural economy of a sugar estate.

In laboratories in general incinerations are made in gas muffle furnaces which are not usually available in tropical sugar houses; but the Swedish paraffin blast lamps are very convenient for use in operations of this nature.

Nitrogenous Bodies.—The determination of the nitrogenous bodies in cane juice is chiefly of interest to the agricultural side of a sugar estate; their determination forms, however, a means of testing the efficiency of any new methods of clarification. Perhaps the most convenient process is Gunning's modification of the original Kjeldahl moist combustion process. In this process the material under analysis is heated with a mixture of sulphuric acid and potassium sulphate, until the solution has become colourless or of a pale straw colour. As applied to cane juice the process may be thus conducted: 20 c.c. of juice are evaporated to small bulk and washed into a 300 c.c. hard glass flask with 20 c.c. of concentrated sulphuric acid; add, in small quantities at a time, 10 grams powdered potassium sulphate; heat very gently over a small flame till frothing stops, and then raise the temperature and allow to boil till the contents of the flask are colourless; transfer to a hard glass litre flask, add caustic soda to distinct alkalinity and distil until all the ammonia is given off, collecting the distillate in 50 c.c. of decinormal acid; determine the excess of acid remaining by titration with decinormal alkali; bumping nearly always occurs near the end of the distillation, and to prevent this the latter operation may be carried out by a current of steam, the flask itself being gently heated by a small flame. The caustic soda should be introduced through a stoppered thistle funnel and the distillation flask provided with a safety bulb to prevent any of the contents of the flask being carried over mechanically. The sulphuric acid used should be tested by means of a blank experiment for nitrogen and the quantity found deducted from subsequent determinations.

Acidity and Alkalinity.—When making high-class consumption sugars, juices are boiled with a reaction either neutral or faintly

acid, and as carelessness may lead to serious loss by inversion, the acidity of the juice as it enters the evaporators should be systematically controlled. Two methods may be used:—

1. 100 c.c. of the juice are titrated from a burette with decinormal alkali; to the juice a few drops of phenolphthalein solution are added, the neutralisation of the excess of acid being shown by the appearance of a pink colouration. The juice may be conveniently contained in a white porcelain basin. In this method the juice is alkaline to litmus before the appearance of the pink colour.

2. To 50 c.c. of the juice an excess of alkali is added and the volume completed to 100 c.c. To successive further quantities of 50 c.c. varying quantities of decinormal alkali are added and the volume completed to 100 c.c. The minimum quantity of alkali that gives a juice of the same tint as that to which an excess of alkali was added, is a measure of the acidity of the juice. The tint may be observed in small test tubes of about half-an-inch diameter.

The point of exact neutrality in cane juice is hard to determine, the change not being sharp, but a dirty olive-green colour obtaining over as many as 4 to 5 c.c. of decinormal alkali; and when indicators are used the change is masked by the colour of the juice.

Whether inversion is occurring or not may be easily determined as follows:—50 c.c. of the finally tempered juice after cooling is polarised as usual; a second 50 c.c. of the same sample is kept on a water bath at a temperature of 100°C. for thirty minutes, cooled and polarised; if no inversion is taking place the two readings should be identical.

Carbonated Juices.—The carbonatation process, which is but sparingly used in cane sugar factories, requires special methods for its control; an abstract of the methods employed in beet sugar factories may be given here.

It is customary to determine the alkalinity of the juice of the first and second saturation in terms of lime as CaO ; as this determination has to be done rapidly, special methods of moderate accuracy are employed. One of the simplest and most convenient is Vivien's. A standard acid containing 875 gram H_2SO_4 per 1000 c.c. is prepared; the acid is standardised against decinormal alkali; 10 c.c. of the latter are equivalent to 56 c.c. of the acid which, when exactly made up, neutralises volume for volume a solution containing 05 gram lime

per 1000 c.c.; the indicator employed is phenophthalein, which is placed in the stock of standard acid. The tube (*Fig. 125*) is filled to the zero mark, and the standard acid added; as long as lime is in excess the juice remains red, becoming finally colourless when the lime is neutralised. Each ten divisions in the tube correspond to .1 gram lime per 1000 c.c. For juice of the second saturation a weaker acid only one-fifth the strength of the above is used.

The determination of the total lime in the juice is performed by the usual methods; 100 c.c. juice are heated to boiling, ammonia added in excess and filtered if necessary; the lime is precipitated by ammonium oxalate from the hot solution, boiled for two hours, filtered, washed, dried, and weighed as carbonate or sulphate.



FIG. 125.

The alkalinity of a juice is in part due to caustic soda and potash set free by the action of lime on the salts of the former present in the juice; when it is wished to determine the alkalinity due to lime and to soda and potash, Pellet's method may be used. 1. Determine the total alkalinity by titration with sulphuric acid, using litmus as an indicator and making the titration at the boiling point. 2. To a volume of the juice add an equal bulk of alcohol which will precipitate the lime as an insoluble saccharate; filter, and in an integral part of the filtrate determine the alkalinity; the latter is due to free caustic potash and soda but is expressed as lime for purposes of convenience; by determining the total lime, the combined lime can be likewise obtained.

THE DETERMINATION OF SUGAR BY CLERGET'S METHOD.—The disturbing effect of the simultaneous presence of glucose and levulose in cane sugar juices and products has already been referred to. A method whereby their effect can be eliminated was devised by Clerget in 1849; cane sugar, when heated with acids, is quantitatively converted into equal portions of dextrose and levulose, a solution of cane sugar, originally dextrorotatory, is after treatment with acids found to be laevorotatory, the left handed rotation of the levulose being greater than the right handed rotation of the dextrose. Clerget found that a solution of 16.471 grams (the then accepted normal weight) of sugar per 100 c.c. gave on inversion a reading at 0° C. of — 44 degrees, the rotation decreasing .5 degree for every 1° C. rise in temperature. If a be the polarisation of a sugar before inversion and b its polarisation after inversion, the true percentage of sugar is given by the formula $\frac{(a-b)}{144 - \frac{t}{2}}$, t being the temperature in the centigrade scale at

which the readings are taken. This method is of great importance and has been very carefully reviewed by many chemists; the process as detailed by Herzfeld and generally accepted is as follows:—

The normal weight of the sugar under examination is weighed out, made up to 100 c.c. and polarised; the reading obtained—"direct polarisation"—is noted. The inversion process is made thus:—Dissolve the half normal weight (13.024 grms.) of the sugar in 75 c.c. of water in a 100 c.c. flask; add 5 c.c. of a 35% solution of hydrochloric acid, and place the flask in a water bath at 70° C.; shake continually and the contents of the flask will reach a temperature of 67° C.—70° C. in about 2½ minutes; keep at this temperature for five minutes; remove, cool rapidly, make up to 100 c.c., and polarise in a 20 c.m. tube; multiply the reading by two to reduce the result to the same basis as the direct polarisation; this reading is the reading "after inversion." If a = direct polarisation, b = polarisation after inversion, t the temperature of observation in degrees Centigrade, the percentage of sugar, S , is given by the formula: $S = \frac{100(a-b)}{142.66 - t}$.

If a different concentration of sugar be used than the normal, the formula appears thus: $S = \frac{100(a-b)}{141.84 + \frac{c}{40} - \frac{t}{2}}$, c being the reading

after inversion in the 20 c.m. tube, corrected to the same basis as the direct polarisation.

The one essential in using Clerget's process is that the conditions of inversion, *i.e.*, the temperature and time of heating and the concentration of the acid, be rigidly adhered to. In other matters detail may be varied as convenient.

Instead of inverting by means of hydrochloric acid, inversion through the agency of yeast has been worked out by O'Sullivan and Thompson. Their procedure is as follows:—50 c.c. of the solution under analysis are raised to 55° C. and kept at that temperature on a water bath. Some brewers' yeast, in quantity $\frac{1}{10}$ of the sugar in the solution, is pressed in a towel, placed in the flask and well stirred; the whole is kept on a water bath at 55° C. for four hours, cooled to 15.5° C., clarified with a little alumina cream, made up to 100 c.c. and polarised; and second polarisation is made after 24 hours to show that inversion is complete. If a = number of divisions indicated by a polariscope reading for a 200 mm. tube, a' the same after inversion, m the number of divisions of the polariscope scale which 200 mm. of the sugar solution (containing one gram of cane sugar per 100 c.c.) alter at 15.5° C. on being inverted, in the Ventzke scale one gram of cane sugar per 100 c.c. indicates + 3.84 divisions, and after inversion — 1.34 divisions; m is therefore 5.18. Then if P = weight of cane sugar present in 100 c.c. of the original solution,

$$P = \frac{a - 2a'}{m}$$

This formula is essentially the one described above, and there is no reason why the calculation should not be made as described before. The writer has used the locally-occurring wild yeast in Demerara, obtained from a top fermentation in rum distilleries, to make the inversion successfully as described above.

DETERMINATION OF CANE SUGAR AS GLUCOSE.—Cane sugar may be very accurately determined, and the sources of error connected with the polariscopic method eliminated, by determination as glucose. In this method the reducing power of the material is determined before inversion; the material is then inverted as described above, and the reducing power again determined in an aliquot portion; one part of cane sugar gives 1.0526 parts of invert sugar on inversion. From the two analyses the amount of cane sugar as glucose is at once calculated. The methods of determining glucose have been given in a previous chapter. This method is not in general use, since

it requires more time and skill than the simpler polariscopic assay, which is especially suited for technical control. In using this method it is in general customary to submit material to clarification with lead acetate. This process barely seems necessary, as the factor which is required is the *increase* in copper oxide reducing power on inversion. O'Sullivan's and Thompson's method of inversion would seem very suitable for use with this process as opposed to the usual acid inversion process of Clerget, since it is known that the prolonged action of hydrochloric acid results in the destruction of levulose. Any error due to destruction of levulose in the Clerget process is eliminated by always performing the inversion under identical conditions. This process, though logically quite sound, has not, the writer believes, been worked out in detail.

DETERMINATION OF SUGAR DEXTROSE AND LEVULOSE.—The mixture of dextrose and levulose occurring in cane sugar products is usually returned as glucose, and no attempt is made to separate the two bodies; occasionally it may be of interest or importance to make a complete separation, as, for example, the identification of origin of a molasses, beet molasses as a rule containing equal proportions of dextrose and levulose, and cane molasses an excess of dextrose. The following methods amongst others have been used.

The optical activity of levulose decreases with a rise of temperature until at 87.2°C. it is optically inactive; it has been shown by Chandler and Ricketts that this decrease is directly proportional to the rise in temperature; the optical activity of sugar and glucose remains approximately constant with rise of temperature. In the use of this method the mixture of sugars is polarised at a low, and afterwards at an increased, temperature; specially designed polariscope tubes with a water bath to maintain a constant temperature are used; if P and P' are the readings at temperatures C and C' in a 20 cm. tube, then the number of grams of levulose per 100 c.c. is given by the formula

$$\frac{(P - P')100}{(C' - C)1.277}.$$

The amount of cane sugar and the sum total of the dextrose and the levulose are obtained as usual.

The problem can also be solved thus. Let a be the percentage of sugar (Clerget), b the sum of the percentages of dextrose and levulose, c the reading after inversion referred to normal weight in 100 c.c.;

x the percentage of dextrose and y the percentage of levulose. At a temperature of, say, 28°C . such as prevails in a tropical laboratory, where the rotation of cane sugar is put equal to 100, that of dextrose is 79.2 and that of levulose is -137.3 . A mixture of equal weights of dextrose and levulose at this temperature formed from the inversion of unit weight of sugar will polarise -29.0 . It then follows

$$\begin{aligned} .792x - 1.373y - .290a &= c \\ x + y &= b. \end{aligned}$$

In using this method the temperature at which readings are taken must be very carefully observed.

THE ANALYSIS OF MASSE-CUITES AND MOLASSES.

Density.—The density of a masse-cuite has a twofold meaning: firstly the apparent density of the material as it actually exists, a figure required to calculate the weight of the factory product from its cubage, and secondly the true density required in the control of the boiling.

The method used by the writer is as below:—

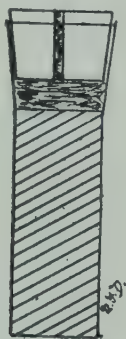


FIG. 126.

A large wide-mouthed vessel of the slope shown in *Fig. 126* is constructed of copper or brass, or even a wide-mouthed bottle may be employed, if the mouth of the vessel is formed sloping inwards and a stopper is ground to accurately fit this mouth; through the centre of the stopper is bored a hole about $\frac{1}{8}$ in. in diameter. Masse-cuite from the pan is allowed to flow into the vessel until about seven-eighths full; the vessel is then allowed to cool until it has reached the temperature at which the factory measurements of masse-cuite are taken, and the weight of masse-cuite determined. Water is then carefully poured over the surface of the masse-cuite till

the vessel is full, the stopper inserted, when the excess of water escapes through the aperture and is wiped off. The method of calculation is shown below :—

	grams.
Weight of vessel and stopper empty	416·35
„ „ „ and water	2163·40
„ water	1747·05
„ vessel, stopper, and masse-cuite	2645·95
„ masse-cuite	2229·60
„ vessel, stopper, masse-cuite, and water	2875·95
„ water above masse-cuite	230
„ water in space occupied by masse-cuite	1517·05
Apparent specific gravity of masse-cuite ..	$\frac{2229·60}{1517·05} = 1·469$

In using this method no attempt is made to remove imprisoned air-bubbles, the object of the determination being to facsimilise the actual working of the factory.

An accurate determination of actual specific gravity of a masse-cuite can be made by this method, using instead of water an indifferent material such as oil. This material is introduced into a wide-mouthed vessel similar to the one already described; an oil of already determined density is poured over it, and the two mixed until air-bubbles are no longer seen to rise. The stirrer may conveniently be a piece of iron rod, of such a length that it may remain in the vessel without interfering with the insertion of the stopper. After removal of the air-bubbles the vessel is filled up with oil and the determination completed as above. An example follows :—

	grams.
Weight of vessel, stopper and stirrer	453·75
„ „ „ „ and oil	1838·35
Specific gravity of oil (water 1·0)	·8550
Weight of oil	1384·95
„ vessel, stopper, stirrer and masse-cuite.	2548·35
„ masse-cuite	2095·65
„ vessel, &c., masse-cuite and oil	2743·20
„ oil above masse-cuite	194·85
„ oil in space occupied by masse-cuite ..	1190·10
Real specific gravity of masse-cuite	$\frac{2095·65}{1190·10} \times ·855 = 1·5056$

In technical control the density of a masse-cuite or molasses is often determined by dilution and taking the degree Balling of the diluted material. An example will make the method clear: 250 grams of a masse-cuite dissolved in water and made up to 1000 c.c. stand at 20.8° Balling; the total solids present in the 1000 c.c. and also in the 250 grams of material used are then $.208 \times 1077.4 = 224.1$; whence the percentage of solids or degree Balling of the masse-cuite is 89.64, corresponding to a density of 1.491. The water per cent. in the masse-cuite is, of course, the difference between 100 and the total solids—in this case, 10.36 %.

This method of determining density, solids and water is not accurate, and is only suited for rapid technical control; a more accurate determination is to dissolve a weighed quantity of masse-cuite in water, absorb it on sand, pumice stone or filter paper, as referred to above in the analysis of the juice, and dry to constant weight.

SUGAR AND GLUCOSE.—The usual process adopted in technical control is to weigh out a suitable quantity of material, dissolve in water, add sufficient basic lead acetate to obtain clarification, make up to 100 c.c., filter and polarise. If w is the weight of material taken, giving a reading r in a 20 c.m. tube, the percentage of sugar is found by calculating $\frac{n}{w} r \times 100$, n being the normal weight for the polariscope; the glucose is determined in the filtrate as described for juice after removal of lead and dilution to a suitable concentration. This rough and ready method of determining sugar and glucose is open to many sources of error, which are greatest with the low after products; amongst these is the error due to the volume of the lead precipitate, that due to precipitation of an insoluble lead levulosate, and that due to the disturbing influence of other active sugars. To make an accurate analysis, the volume of the lead precipitate must be determined by one of the methods already given and the sugar determined by Clerget's process or by determination of glucose before and after inversion; to obtain the glucose correctly, neutral lead acetate must be used in the clarification.

The object of analysis of a first masse-cuite is to compare the amount of sugar recovered here with that originally present in the

juice; the analysis of juice and first masse-cuite should be made on an identical basis, as then the errors introduced (which are in this case small) are the same. For example, if the juice for a certain period contained 18% solids, the amount of masse-cuite weighed out should be sufficient, when made ready for polarisation, to give a solution containing approximately also 18% of solids.

Purity.—The apparent purity of a masse-cuite or molasses is the ratio of sugar to total solids, the latter being found by dilution and spindling, as indicated above, and the sugar being found by direct polarisation; occasionally the purity is given as a combination of the apparent total solids and the sugar, as found by Clerget's method. The true purity is that found after determining the true total solids by drying to constant weight, the sugar being found by Clerget's method or being determined as glucose.

Ash, Alkalinity, and Acidity.—These are determined as already described for juices. Molasses are usually so darkly coloured that any change in their colour is difficult to detect. The following method, due to Buisson, may be used:—Place 25 c.c. of a solution of the material under analysis in a glass stoppered flask; add 10 c.c. of ether, containing a little corallin, and titrate with decinormal acid or alkali; after each addition shake the flask and allow the ether to rise to the surface; an excess of acid is denoted by the ethereal solution being coloured yellow, changing to red with an excess of alkali.

CRYSTALLISED AND DISSOLVED SUGAR.—The total sugar in a masse-cuite or molasses exists in two forms, either separated out as crystals, or still remaining in solution in the necessarily accompanying water; in general two similar juices, similarly treated and boiled to the same water content, will separate out the same amount of crystals, but the actual recovery at the centrifugals may be widely different. For in one case, by skilful pan-boiling, the crystallised sugar is obtained in a form permitting of easy separation from the molasses, and in a second, the presence of fine crystals may cause considerable losses. The determination of the crystallised sugar affords a valuable check on the pan-boiler.

Vivien's Method.—Weigh out about 200 grams of masse-cuite and place in the funnel of the pressure filtering apparatus, as in *Fig. 127*. connect the apparatus to a filter pump, and wash with a cold saturated solution of pure sugar and water until all molasses are removed; transfer the crystals to a tared dish and obtain their weight. Remove about 10 grams and dry to constant weight to determine the water adhering to the crystals. At a temperature of 84° F., for each one part of water 2.125 parts of sugar are dissolved in a saturated solution. This last determination gives data to calculate the weight of washing syrup which has replaced the molasses; an example is appended.



FIG. 127.

Weight of masse-cuite, 200 grams; weight of washed crystals, 175 grams; percentage of water in washed crystals, 6.54. Then total moisture in washed crystals = $\frac{175 \times 6.54}{100} = 12.62$, and wash liquor in washed crystals = $12.62 \times 3.125^* = 35.77$ grams, and weight of crystals $175 - 35.77 = 139.23$ grams, or 69.66% on weight of masse-cuite.

Dupont's Method.—Heat the masse-cuite to a temperature of 80°C. and centrifugal in a small hand machine, the wire basket of which is covered with thin flannel or some similar material; polarise the molasses and the cured sugar and calculate the percentage of crystallised sugar from the following formula: $x = \frac{a - p'}{p - p'}$; where x = weight of crystallised sugar in one part of masse-cuite, a the percentage of sugar in the masse-cuite, p the percentage of sugar in the cured crystals, and p' that in the molasses.

* For a temperature of 84° F.

This formula is applicable for use on the factory scale, provided no water is used in curing, and that the molasses are filtered through flannel before analysis so as to remove fine crystals; if water be used in small quantities and if the amount can be calculated, the sugar percentage of the molasses can be corrected for dilution, but in this case the formula will not give results so correct.

Geerligs' Method.—This method depends on the observation that sugar crystals themselves only contain a trace of ash, the ash of commercial sugars being due to the accompanying molasses; hence, in a masse-cuite the ash is due solely to the molasses. Determine the percentage of ash in the masse-cuite and in its molasses freed from fine grain by filtration through glasswool; as an example, let the masse-cuite contain 2.25% and the molasses 6.07% ash; then the percentage of molasses in the masse-cuite is $\frac{2.25}{6.07} \times 100 = 37.07\%$; the remainder 63.93% being crystallised sugar.

These methods have been described as applicable to masse-cuites; they are, of course, applicable to molasses to determine the quantity of fine grain which has been separated on cooling or is present after having passed through the mesh of the centrifugal basket.

ANALYSIS OF FILTER-PRESS CAKE.

Water.—Dry to constant weight at a temperature of 105° C. The use of a vacuum oven, though permissible, is not so necessary as in the case of juices and molasses, &c.

Sugar.—The amount of insoluble matter in filter-press cake is so considerable that error is introduced if the volume is not allowed for. Well-pressed cake contains on an average 40% of insoluble matter, which occupies per 100 grams about 20 c.c.; the volume occupied by the insoluble matter in 25 grams is then about 5 c.c., and if this quantity be weighed out and made up to 100 c.c. after addition of lead acetate, the polariscope reading will indicate at once the percentage of sugar; or instead, the normal weight may be weighed out and polarised after making up to 105 c.c.

In factories using the carbonatation process, saccharates of lime may occur in the press cake. Before polarisation these must be decomposed; the decomposition can be effected by the passage of a current of carbon dioxide, or more conveniently by the addition of a few drops of acetic acid.

Manurial Value.—The constituents of manurial value are the nitrogen and phosphoric acid; the nitrogen is determined by Kjeldahl's process or one of its modifications, and the phosphoric acid in the ash after incineration.

ANALYSIS OF THE WASTE WATERS.

The waste injection waters from the evaporators and from the calandrias should be systematically tested for the presence of sugar. The volume of the waste waters is so great that very small quantities of sugar may indicate a serious loss. The quantity of sugar, if present at all, is so small as not to be in general capable of detection by the polariscope. Sugar may be detected either by the copper or by the α — naphthol or thymol test. In the former case a litre of waste water is evaporated to small bulk, say to 20 c.c., with the addition of a few drops of hydrochloric acid, and the concentrated product boiled for two minutes, with a quantity of Fehling's solution. The presence of glucose, due originally to the cane sugar, is indicated by a red precipitate of copper oxide; if present in quantity, the glucose may be determined by one or other of the methods already given.

The α — naphthol test is thus carried out. Mix about 1 c.c. of the material to be tested with one or two drops of a 15% solution of α — naphthol in alcohol and place in a small test tube; allow two or three drops of strong sulphuric acid to flow down the side of the test tube and to sink to the bottom; in the presence of sugar the zone of demarcation of the two liquids is marked by a lilac or violet coloration; with thymol, the coloration produced is pink to carmine. This test will detect one part of sugar in 10,000,000 of water and in general all sugar house waste waters will answer to it; very minute quantities of sugar can be estimated by preparing solutions of known sugar percentage, one per 1,000,000, &c., and comparing the tints produced with that obtained with the material under examination under identical conditions.

THE ANALYSIS OF SUGARS.

The routine of the polariscopic test of the commercial sugars produced in the factory is as follows:—

Weigh out exactly the normal weight; dissolve in a little water, pour into 100 c.c. flask, add a few drops of basic lead acetate, make

up to 100 c.c. with water, filter and polarise in a 20 cm. tube; the polariscope reading gives the percentage of sugar. German silver basins with an elongated lip adapted for convenient pouring are usually provided with polariscope outfits, or can be obtained from dealers. The balance used need only be sensible to .01 gram, as an error of this magnitude (.01 gram) could not be detected in the polariscope. This method of analysis is open to all the sources of inaccuracy discussed already; with high grade first products these sources of error are very small, but they become appreciable with low grade after products; sugars are, however, bought and sold on this convenient basis. Where accuracy and not commercial convenience is required, the Clerget process should be used and the correction for volume of lead precipitate applied.

The ash and water in sugars are determined as already indicated for *masse-cuites*.

THE ANALYSIS OF LIMESTONE AND LIME.

It is not general for sugar factories to prepare their own lime, but in the carbonatation process it is necessary, and where a supply of limestone is abundant, as in Mauritius and Barbados, it is cheaper to burn lime than to import. The choice of limestone is important and it is advisable also to keep a check on the composition of the purchased lime.

Moisture.—Dry 1—2 grams to constant weight.

Sand, insoluble and organic matter.—Dissolve about 1 gram in hydrochloric acid, filter through a tared filter paper, wash and dry at 100° C.; weigh, giving the weight of sand, etc., ignite and weigh obtaining the sand, the difference of the two weights giving the organic matter.

Soluble Silica.—Evaporate to complete dryness the filtrate from the determination of the sand, &c.; moisten the residue and again evaporate to dryness, keeping the residue at a temperature of 120° C. for an hour after the residue is apparently dry; take up with hot water, filter and wash till free of chlorides; dry, ignite, and weigh the residue as SiO_2 .

Insoluble Silica.—Mix the residue obtained in the determination of the sand with four or five times its weight of fusion mixture, composed of molecular proportions of sodium and potassium carbonates, and keep at a red heat for half an hour after effervescence

has ceased; dissolve out with dilute hydrochloric acid, evaporate to dryness and determine the silica as before.

Iron, Alumina.—Mix the filtrates from the determinations of soluble and insoluble silica; evaporate to convenient bulk, add ammonia till alkaline, and heat till the solution smells only faintly of ammonia; filter while hot; wash, dry, ignite, and weigh the precipitate as $\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$. If there be present any large quantity of iron and alumina after decanting off the supernatant liquid, the precipitate should be dissolved in hydrochloric acid and re-precipitated.

Lime.—Precipitate the lime in the filtrate from the iron and alumina while boiling hot with ammonium oxalate; allow to stand for six hours, and filter, wash, dry and ignite the precipitate to constant weight and weigh as CaO ; convert the lime to sulphate or carbonate by evaporation to dryness with either sulphate or carbonate of ammonia and again ignite, and weigh as CaSO_4 , or as CaCO_3 :
 $\text{CaCO}_3 \times .56 = \text{CaO}$; $\text{CaSO}_4 \times .4118 = \text{CaO}$.

Magnesia.—Precipitate the magnesia in the filtrate from the lime determination as phosphate by the addition of sodium phosphate; agitate the solution violently, and allow to stand for 12 hours; filter, wash with dilute ammonia, dry, ignite strongly, and weigh as $\text{Mg}_2 \text{P}_2 \text{O}_7$: $\text{Mg}_2 \text{P}_2 \text{O}_7 \times .3604 = \text{Mg O}$.

As magnesia is detrimental to the value of good limestone, Geerligs has given a scheme for its rapid estimation. Two grams are dissolved in hydrochloric acid, evaporated to complete dryness, the residue brought into solution with hydrochloric acid, boiled after the addition of a few drops of nitric acid, and evaporated to small bulk. An excess of calcium carbonate is added to precipitate iron and alumina, the precipitate filtered off, and the filtrate collected in a flask to which an excess of lime water is added; the flask is filled nearly to the neck and set aside to settle; the supernatant liquid is decanted through a filter, and the precipitate washed by decantation. The precipitate from the lime water contains the magnesia; it is dissolved in hydrochloric acid, the lime precipitated as before by ammonium oxalate, and the magnesia determined in the filtrate.

Sulphuric Acid.—Dissolve about 5 grams in dilute hydrochloric acid; separate the silica as before, and in the hot filtrate precipitate the sulphuric acid by barium chloride; allow to settle for six

hours, filter, wash, dry, ignite, and weigh as BaSO_4 ; $\text{BaSO}_4 \times \cdot 3427 = \text{SO}_3$; $\text{BaSO}_4 \times \cdot 5828 = \text{CaSO}_4$.

The method of Sundstrom for the rapid estimation of magnesia in limestones is as follows:—

Weigh out one gram of material into a small dish, add about 100 c.c. water and 25 c.c. of normal hydrochloric acid; heat to boiling, allow to cool and titrate the excess of acid with normal caustic soda, thus obtaining the quantity of acid required to neutralise the carbonates of lime and magnesia. The lime is determined as usual and calculated to carbonate; if the percentage of calcium carbonate be divided by five, the quotient will give the number of c.c. of normal hydrochloric acid required to neutralise the calcium carbonate; the difference between that found above as necessary to neutralise the lime and magnesia carbonates, and the calculated number of c.c. necessary for the lime alone, gives the number of c.c. requisite to neutralise the magnesia carbonate; this number, multiplied by 4·2, gives the percentage of magnesia carbonate.

The analysis of the lime is performed exactly as for limestone; very often large quantities of alkalis are found in the lime, especially if the limestone has been burnt with wood fuel in a short flame kiln. In addition to the chemical analysis of the lime, a mechanical bulk analysis for the determination of stones, unburnt limestone, &c., may be made; very considerable quantities of these materials are often found. The following are special methods of lime analysis:—

Free Lime.—Dissolve about one gram of lime in a 25 to 30% solution of sugar; make up to definite volume, filter and titrate an aliquot part of the filtrate with normal acid.

Unburned and Slaked Lime.—Dissolve about one gram of lime in a definite quantity of normal acid and determine the excess of acid by titration with normal alkali; the difference between the total lime as thus found and the free lime as found above gives the unburnt lime.

Degener-Lunge Method.—Slake about one gram of lime with water and titrate with normal acid, using phenacetoline as indicator. The point at which the indicator changes from yellow to red marks the neutralisation of the free lime; the addition of acid being continued, the point at which the unburnt and slaked lime are neutralised is marked by a change from red to golden yellow.

Below are collected certain tables of use in sugar house work.

TABLE GIVING A COMPARISON OF DEGREES BRIX AND SPECIFIC GRAVITY AT 84° F. COMPARED WITH
WATER AT 60° F.*

$$\text{Formula:—Specific Gravity} = \frac{272}{272 - B^{\circ}}$$

	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	1.0000	1.0004	1.0007	1.0011	1.0014	1.0017	1.0021	1.0024	1.0028	1.0032
1	1.0036	1.0039	1.0043	1.0047	1.0051	1.0054	1.0058	1.0062	1.0065	1.0070
2	1.0074	1.0077	1.0081	1.0085	1.0089	1.0092	1.0096	1.0000	1.0004	1.0008
3	1.0112	1.0115	1.0119	1.0123	1.0126	1.0130	1.0134	1.0138	1.0141	1.0145
4	1.0149	1.0152	1.0156	1.0160	1.0164	1.0167	1.0171	1.0175	1.0179	1.0183
5	1.0187	1.0191	1.0194	1.0198	1.0202	1.0205	1.0209	1.0213	1.0217	1.0221
6	1.0225	1.0229	1.0233	1.0237	1.0240	1.0244	1.0248	1.0252	1.0256	1.0260
7	1.0264	1.0268	1.0272	1.0275	1.0279	1.0283	1.0287	1.0291	1.0295	1.0299
8	1.0303	1.0307	1.0311	1.0314	1.0318	1.0322	1.0326	1.0330	1.0334	1.0338
9	1.0342	1.0346	1.0350	1.0354	1.0358	1.0362	1.0366	1.0370	1.0374	1.0378
10	1.0382	1.0386	1.0390	1.0394	1.0398	1.0402	1.0406	1.0410	1.0414	1.0418
11	1.0422	1.0426	1.0430	1.0434	1.0438	1.0442	1.0446	1.0450	1.0454	1.0458
12	1.0462	1.0466	1.0470	1.0474	1.0478	1.0482	1.0486	1.0490	1.0494	1.0498
13	1.0502	1.0506	1.0510	1.0514	1.0518	1.0522	1.0526	1.0530	1.0534	1.0538
14	1.0543	1.0547	1.0551	1.0555	1.0559	1.0563	1.0567	1.0571	1.0575	1.0579
15	1.0584	1.0588	1.0592	1.0596	1.0600	1.0604	1.0608	1.0612	1.0616	1.0621
16	1.0625	1.0629	1.0633	1.0637	1.0641	1.0646	1.0650	1.0654	1.0658	1.0662
17	1.0666	1.0670	1.0674	1.0679	1.0683	1.0687	1.0692	1.0696	1.0700	1.0704
18	1.0709	1.0713	1.0717	1.0721	1.0725	1.0730	1.0734	1.0738	1.0742	1.0747
19	1.0751	1.0755	1.0759	1.0764	1.0768	1.0772	1.0777	1.0781	1.0785	1.0789
20	1.0794	1.0798	1.0802	1.0806	1.0810	1.0815	1.0819	1.0823	1.0827	1.0831
21	1.0836	1.0840	1.0844	1.0848	1.0853	1.0858	1.0862	1.0867	1.0871	1.0875

22	1.0880	1.0884	1.0889	1.0893	1.0898	1.0902	1.0907	1.0911	1.0916	1.0920
23	1.0924	1.0928	1.0933	1.0938	1.0942	1.0947	1.0951	1.0955	1.0959	1.0963
24	1.0968	1.0972	1.0977	1.0981	1.0986	1.0990	1.0994	1.0999	1.1003	1.1007
25	1.1012	1.1016	1.1021	1.1025	1.1029	1.1034	1.1039	1.1043	1.1048	1.1052
26	1.1057	1.1061	1.1066	1.1070	1.1075	1.1079	1.1084	1.1089	1.1093	1.1098
27	1.1102	1.1106	1.1109	1.1113	1.1116	1.1119	1.1123	1.1127	1.1131	1.1135
28	1.1147	1.1151	1.1156	1.1160	1.1165	1.1169	1.1174	1.1178	1.1183	1.1188
29	1.1198	1.1202	1.1207	1.1211	1.1216	1.1221	1.1225	1.1229	1.1234	1.1238
30	1.1239	1.1244	1.1249	1.1253	1.1258	1.1262	1.1267	1.1271	1.1276	1.1281
31	1.1286	1.1290	1.1295	1.1300	1.1304	1.1309	1.1314	1.1319	1.1323	1.1328
32	1.1333	1.1337	1.1342	1.1347	1.1352	1.1356	1.1361	1.1366	1.1370	1.1375
33	1.1380	1.1384	1.1389	1.1394	1.1399	1.1404	1.1409	1.1413	1.1418	1.1423
34	1.1428	1.1432	1.1437	1.1442	1.1447	1.1452	1.1457	1.1461	1.1466	1.1471
35	1.1471	1.1481	1.1486	1.1491	1.1496	1.1501	1.1506	1.1511	1.1516	1.1521
36	1.1528	1.1530	1.1535	1.1540	1.1545	1.1550	1.1555	1.1560	1.1565	1.1570
37	1.1574	1.1579	1.1584	1.1589	1.1594	1.1599	1.1604	1.1609	1.1614	1.1619
38	1.1624	1.1629	1.1634	1.1639	1.1644	1.1649	1.1654	1.1659	1.1664	1.1669
39	1.1674	1.1679	1.1684	1.1689	1.1694	1.1699	1.1704	1.1709	1.1714	1.1719
40	1.1724	1.1730	1.1735	1.1740	1.1745	1.1750	1.1755	1.1760	1.1765	1.1770
41	1.1775	1.1781	1.1786	1.1791	1.1796	1.1801	1.1806	1.1811	1.1816	1.1821
42	1.1826	1.1832	1.1837	1.1842	1.1847	1.1852	1.1857	1.1862	1.1867	1.1872
43	1.1878	1.1884	1.1889	1.1894	1.1899	1.1904	1.1909	1.1915	1.1920	1.1925
44	1.1930	1.1936	1.1941	1.1946	1.1951	1.1956	1.1961	1.1967	1.1972	1.1978
45	1.1982	1.1988	1.1993	1.1998	1.2004	1.2009	1.2014	1.2019	1.2025	1.2030
46	1.2035	1.2041	1.2046	1.2051	1.2057	1.2062	1.2068	1.2073	1.2079	1.2084
47	1.2089	1.2095	1.2100	1.2105	1.2111	1.2116	1.2122	1.2127	1.2133	1.2138
48	1.2143	1.2149	1.2154	1.2159	1.2165	1.2170	1.2176	1.2181	1.2187	1.2192

* This standard is adopted so as to retain the weight of a gallon of water exactly at ten pounds.

TABLE GIVING A COMPARISON OF DEGREES BRIX AND SPECIFIC GRAVITY AT 84°F. COMPARED WITH
WATER AT 60°F.*—Continued.

$$\text{Formula :—Specific Gravity} = \frac{272}{272 - B^{\circ}}$$

	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
49.. ..	1.2197	1.2203	1.2208	1.2214	1.2219	1.2225	1.2230	1.2236	1.2241	1.2247
50	1.2252	1.2258	1.2263	1.2269	1.2274	1.2280	1.2285	1.2291	1.2296	1.2302
51.. ..	1.2307	1.2313	1.2319	1.2324	1.2330	1.2336	1.2341	1.2347	1.2352	1.2358
52	1.2363	1.2369	1.2374	1.2380	1.2386	1.2391	1.2397	1.2403	1.2408	1.2414
53.. ..	1.2420	1.2426	1.2431	1.2437	1.2443	1.2448	1.2454	1.2460	1.2465	1.2471
54	1.2477	1.2483	1.2488	1.2494	1.2500	1.2505	1.2511	1.2517	1.2522	1.2528
55.. ..	1.2534	1.2540	1.2546	1.2552	1.2557	1.2562	1.2568	1.2574	1.2580	1.2586
56	1.2592	1.2598	1.2604	1.2610	1.2616	1.2621	1.2627	1.2633	1.2639	1.2645
57.. ..	1.2651	1.2657	1.2663	1.2669	1.2675	1.2680	1.2686	1.2692	1.2698	1.2704
58	1.2710	1.2716	1.2722	1.2728	1.2734	1.2740	1.2746	1.2752	1.2758	1.2764
59.. ..	1.2770	1.2776	1.2782	1.2788	1.2794	1.2800	1.2806	1.2812	1.2818	1.2824
60	1.2830	1.2836	1.2842	1.2848	1.2854	1.2860	1.2866	1.2872	1.2878	1.2883
61.. ..	1.2889	1.2895	1.2901	1.2907	1.2913	1.2919	1.2925	1.2931	1.2938	1.2945
62	1.2952	1.2958	1.2964	1.2970	1.2977	1.2983	1.2989	1.2995	1.3002	1.3008
63.. ..	1.3014	1.3021	1.3027	1.3033	1.3039	1.3045	1.3052	1.3058	1.3064	1.3070
64	1.3076	1.3083	1.3089	1.3095	1.3102	1.3108	1.3115	1.3121	1.3128	1.3134
65.. ..	1.3140	1.3147	1.3153	1.3159	1.3166	1.3173	1.3179	1.3186	1.3192	1.3198
66	1.3204	1.3210	1.3217	1.3223	1.3230	1.3236	1.3243	1.3249	1.3256	1.3262
67.. ..	1.3268	1.3275	1.3281	1.3288	1.3294	1.3301	1.3307	1.3313	1.3320	1.3326
68	1.3333	1.3340	1.3347	1.3353	1.3359	1.3366	1.3373	1.3380	1.3386	1.3393
69.. ..	1.3399	1.3406	1.3413	1.3419	1.3426	1.3433	1.3440	1.3446	1.3453	1.3459
70	1.3465	2.3472	1.3478	1.3485	1.3492	1.3498	1.3505	1.3512	1.3518	1.3525
71.. ..	1.3532	1.3539	1.3546	1.3552	1.3559	1.3566	1.3573	1.3579	1.3586	1.3593

72	1.3600	1.3607	1.3613	1.3620	1.3627	1.3634	1.8640	1.3647	1.3654	1.3661
73	1.3668	1.3675	1.3682	1.3689	1.3695	1.3702	1.3709	1.3716	1.3723	1.3730
74	1.3737	1.3744	1.3751	1.3758	1.3765	1.3772	1.3779	1.3786	1.3793	1.3800
75	1.3807	1.3814	1.3821	1.3828	1.3835	1.3842	1.3849	1.3856	1.3863	1.3870
76	1.3878	1.3885	1.3892	1.3899	1.3906	1.3913	1.3920	1.3927	1.3935	1.3942
77	1.3949	1.3956	1.3963	1.3971	1.3978	1.3985	1.3992	1.3999	1.4006	1.4013
78	1.4021	1.4028	1.4036	1.4043	1.4050	1.4057	1.4065	1.4072	1.4079	1.4086
79	1.4093	1.4101	1.4108	1.4115	1.4123	1.4130	1.4138	1.4145	1.4152	1.4160
80	1.4167	1.4175	1.4182	1.4190	1.4197	1.4205	1.4212	1.4220	1.4227	1.4234
81	1.4241	1.4249	1.4256	1.4264	1.4271	1.4279	1.4287	1.4294	1.4302	1.4309
82	1.4316	1.4324	1.4331	1.4339	1.4364	1.4354	1.4361	1.4369	1.4376	1.4384
83	1.4391	1.4399	1.4406	1.4414	1.4422	1.4429	1.4437	1.4445	1.4452	1.4460
84	1.4468	1.4476	1.4483	1.4491	1.4499	1.4506	1.4514	1.4522	1.4529	1.4537
85	1.4545	1.4553	1.4560	1.4568	1.4576	1.4584	1.4592	1.4599	1.4607	1.4615
86	1.4623	1.4631	1.4638	1.4646	1.4654	1.4662	1.4670	1.4678	1.4686	1.4694
87	1.4702	1.4710	1.4718	1.4726	1.4734	1.4742	1.4750	1.4758	1.4766	1.4774
88	1.4782	1.4789	1.4798	1.4806	1.4814	1.4822	1.4831	1.4839	1.4847	1.4855
89	1.4863	1.4871	1.4879	1.4888	1.4896	1.4904	1.4912	1.4921	1.4929	1.4937
90	1.4945	1.4953	1.4962	1.4970	1.4978	1.4986	1.4995	1.5003	1.5011	1.5019
91	1.5027	1.5035	1.5043	1.5052	1.5060	1.5069	1.5077	1.5086	1.5094	1.5103
92	1.5111	1.5119	1.5128	1.5136	1.5145	1.5153	1.5162	1.5170	1.5179	1.5187
93	1.5195	1.5203	1.5212	1.5220	1.5229	1.5237	1.5246	1.5255	1.5263	1.5272
94	1.5281	1.5290	1.5298	1.5307	1.5315	1.5324	1.5333	1.5341	1.5350	1.5358
95	1.5367	1.5376	1.5385	1.5393	1.5402	1.5410	1.5419	1.5429	1.5435	1.5445
96	1.5454	1.5462	1.5471	1.5480	1.5489	1.5498	1.5507	1.5516	1.5525	1.5534
97	1.5543	1.5552	1.5561	1.5570	1.5579	1.5588	1.5597	1.5606	1.5615	1.5623
98	1.5632	1.5641	1.5650	1.5659	1.5668	1.5677	1.5686	1.5696	1.5704	1.5713
99	1.5722	1.5731	1.5740	1.5749	1.5759	1.5768	1.5777	1.5786	1.5795	1.5804

* This standard is adopted so as to retain the weight of a gallon of water exactly at ten pounds.

TABLE SHOWING THE EXPANSION OF SUGAR SOLUTIONS.
(Gerlach.)

Temperature C°.	10 per cent.	20 per cent.	30 per cent.	40 per cent.	50 per cent.
0	1·0000	1·0000	1·0000	1·0000	1·0000
5	1·0004	1·0007	1·0009	1·0012	1·0016
10	1·0012	1·0016	1·0021	1·0026	1·0032
15	1·0021	1·0028	1·0034	1·0042	1·0050
20	1·0033	1·0041	1·0049	1·0058	1·0069
25	1·0048	1·0057	1·0066	1·0075	1·0088
30	1·0064	1·0074	1·0084	1·0094	1·0110
35	1·0082	1·0092	1·0103	1·0114	1·0132
40	1·0101	1·0112	1·0124	1·0136	1·0156
45	1·0122	1·0134	1·0146	1·0160	1·0180
50	1·0145	1·0156	1·0170	1·0184	1·0204
55	1·0170	1·0183	1·0196	1·0210	1·0229
60	1·0197	1·0209	1·0222	1·0235	1·0253
65	1·0225	1·0236	1·0249	1·0261	1·0278
70	1·0255	1·0265	1·0277	1·0287	1·0306
75	1·0284	1·0295	1·0306	1·0316	1·0332
80	1·0316	1·0325	1·0335	1·0345	1·0360
85	1·0347	1·0355	1·0365	1·0375	1·0388
90	1·0379	1·0387	1·0395	1·0405	1·0417
95	1·0411	1·0418	1·0425	1·0435	1·0445
100	1·0442	1·0450	1·0456	1·0465	1·0477

TABLE SHOWING THE SOLUBILITY OF SUGAR IN WATER.
(Herzfeld.)

Temperature. C°.	Sugar per cent.	Temperature C°.	Sugar per cent.	Temperature C°.	Sugar per cent.
0	64.18	35	69.55	70	76.22
5	64.87	40	70.42	75	77.27
10	65.58	45	71.32	80	78.36
15	66.53	50	72.25	85	79.46
20	67.09	55	73.20	90	80.61
25	67.89	60	74.18	95	81.77
30	68.80	65	75.88	100	82.97

TABLE SHOWING THE SOLUBILITY OF LIME IN SUGAR SOLUTIONS.

Sugar in 100 parts of Water.	Density of Syrup.	Density after saturation with Lime.	Residue dried at 120° C. Per cent. of Lime.	Residue dried at 120° C. Per cent. of Sugar.
5	1.018	1.026	15.3	84.7
10	1.036	1.053	18.1	81.9
15	1.052	1.080	18.5	81.5
20	1.068	1.104	18.8	81.2
25	1.082	1.128	19.8	80.2
30	1.096	1.148	20.1	79.9
35	1.110	1.166	20.5	79.5
40	1.122	1.179	21.0	79.0

TABLE SHOWING THE SOLUBILITY OF SALTS IN SUGAR SOLUTIONS.
(Jacobsthal.)

Solution containing	5% Sugar.	10% Sugar.	15% Sugar.	20% Sugar.	25% Sugar.
	Grams.	Grams.	Grams.	Grams.	Grams.
Calcium sulphate	2.095	1.946	1.593	1.539	1.333
„ carbonate ..	0.027	0.036	0.024	0.022	0.008
„ oxalate	0.033	0.047	0.012	0.008	0.001
„ phosphate ..	0.029	0.028	0.014	0.018	0.005
„ citrate	1.813	1.578	1.505	1.454	1.454
Magnes. carbonate ..	0.317	0.199	0.194	0.213	0.284

CAUSTIC SODA AT 82.5° F. (Geerligs.)

Percentage of Soda.	Specific Gravity of a percentage of Na ₂ O.	Specific Gravity of a percentage of NaOH.	Percentage of Soda.	Specific Gravity of a percentage of Na ₂ O.	Specific Gravity of a percentage of NaOH.
1	1.012	1.009	31	1.434	1.339
2	1.027	1.020	32	1.446	1.347
3	1.040	1.032	33	1.458	1.359
4	1.055	1.043	34	1.471	1.370
5	1.071	1.056	35	1.484	1.380
6	1.086	1.067	36	1.496	1.391
7	1.101	1.078	37	1.511	1.401
8	1.116	1.089	38	1.526	1.411
9	1.129	1.100	39	1.539	1.422
10	1.142	1.112	40	1.554	1.433
11	1.158	1.123	41	1.566	1.443
12	1.172	1.133	42	1.579	1.452
13	1.187	1.145	43	1.593	1.464
14	1.200	1.156	44	1.606	1.474
15	1.215	1.167	45	1.617	1.484
16	1.230	1.178	46	1.632	1.495
17	1.241	1.184	47	1.645	1.503
18	1.254	1.198	48	1.658	1.514
19	1.266	1.209	49	1.673	1.524
20	1.284	1.221	50	1.685	1.535
21	1.296	1.234	51	1.700	1.545
22	1.311	1.243	52	1.714	1.555
23	1.325	1.254	53	1.725	1.565
24	1.337	1.265	54	1.740	1.575
25	1.351	1.275	55	1.755	1.586
26	1.365	1.286	56	1.770	1.596
27	1.374	1.296	57	1.780	1.606
28	1.391	1.306	58	1.795	1.617
29	1.406	1.317	59	1.810	1.628
30	1.420	1.328	60	1.825	1.638

SODIUM CARBONATE AT 82.5° F. (Schiff.)

Specific Gravity.	Percentage of $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$.	Percentage of Na_2CO_3 .	Specific Gravity.	Percentage of $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$.	Percentage of Na_2CO_3 .
1.0038	1	.370	1.1035	26	9.635
1.0076	2	.741	1.1076	27	10.005
1.0114	3	1.112	1.1117	28	10.376
1.0153	4	1.482	1.1158	29	10.746
1.0192	5	1.853	1.1210	30	11.118
1.0231	6	2.223	1.1242	31	11.448
1.0270	7	2.574	1.1284	32	11.859
1.0309	8	2.965	1.1326	33	12.230
1.0348	9	3.335	1.1368	34	12.600
1.0388	10	3.706	1.1410	35	12.971
1.0428	11	4.076	1.1452	36	13.341
1.0468	12	4.447	1.1494	37	13.712
1.0508	13	4.817	1.1536	38	14.082
1.0548	14	5.188	1.1578	39	14.453
1.0588	15	5.558	1.1620	40	14.824
1.0628	16	5.928	1.1662	41	15.195
1.0668	17	6.299	1.1704	42	15.566
1.0708	18	6.670	1.1746	43	15.936
1.0748	19	7.041	1.1788	44	16.307
1.0789	20	7.412	1.1830	45	16.677
1.0830	21	7.782	1.1873	46	17.048
1.0871	22	8.153	1.1916	47	17.418
1.0912	23	8.523	1.1959	48	17.789
1.0953	24	8.894	1.2002	49	18.159
1.0994	25	9.264	1.2045	50	18.530

PHOSPHORIC ACID AT 82.5° F. (Geerligs.)

Specific Gravity.	Percentage of H_3PO_4 .	Percentage of P_2O_5 .	Specific Gravity.	Percentage of H_3PO_4 .	Percentage of P_2O_5 .
1.0537	10	7.260	1.1856	30	21.780
1.0597	11	7.986	1.1928	31	22.506
1.0658	12	8.712	1.2000	32	23.232
1.0719	13	9.438	1.2073	33	23.958
1.0781	14	10.164	1.2148	34	24.664
1.0844	15	10.890	1.2224	35	25.410
1.0907	16	11.616	1.2298	36	26.136
1.0970	17	12.342	1.2375	37	26.862
1.1032	18	13.068	1.2453	38	27.588
1.1097	19	13.744	1.2532	39	28.314
1.1163	20	14.520	1.2611	40	29.040
1.1208	21	15.246	1.2698	41	29.766
1.1296	22	15.972	1.2772	42	30.492
1.1364	23	16.698	1.2854	43	31.218
1.1432	24	17.424	1.2936	44	31.944
1.1501	25	18.150	1.3018	45	32.670
1.1571	26	18.876	1.3102	46	33.496
1.1641	27	19.602	1.3186	47	34.222
1.1712	28	20.328	1.3272	48	35.674
1.1784	29	21.054			

LEAD ACETATE AT 15° C. (Gerlach.)

Specific Gravity.	Percentage of Lead Acetate.	Specific Gravity.	Percentage of Lead Acetate.	Specific Gravity.	Percentage of Lead Acetate.
1.0127	2	1.0939	14	1.1704	24
1.0255	4	1.1084	16	1.1869	26
1.0386	6	1.1234	18	1.2040	28
1.0520	8	1.1384	20	1.2211	30
1.0654	10	1.1544	22	1.2395	32
1.0796	12				

CHAPTER XXIV.

FERMENTATION IN SPECIAL REFERENCE TO THE SUGAR HOUSE.

The word fermentation, according to its derivation, means boiling and is due to the similarity in appearance that saccharine solutions undergoing alcoholic fermentation present to ebullition; popularly speaking, the term is applied only to the alcoholic fermentation of sugar solutions, but it may be defined as any process which proceeds under the influence of micro-organisms. Of other fermentation processes may be instanced lactic fermentation under which milk turns sour; the formation of indigo from bodies present in the plant; the sweating of cocoa; the formation of vinegar from wine lees, and many other technical processes: under this heading is described the alcoholic fermentation and sundry other fermentations of interest to the sugar manufacturer.

Alcoholic fermentation in general takes place under the influence of organisms known popularly as yeast and which are included in the family *saccharomyces*. The spongy mass which rises to the surface of fermenting vats consists of an infinite number of unicellular organisms. Their size varies; in general they are from 8—9 μ ($\mu = \frac{1}{1000}$ millimeter = $\frac{1}{25000}$ inch) in diameter, but those occurring in the West Indies and Demerara are much smaller, only averaging from 4—5 μ in diameter. A cell of yeast when placed in a nutrient solution, such as a solution of glucose containing nitrogen and certain mineral constituents, multiplies very rapidly. Reproduction is effected by budding or gemmation; that is to say, when viewed under the microscope, an excrescence appears on one side of the cell, which grows and eventually breaks off from the mother cell; this process is carried on to infinity. In the yeasts common to Europe, the cells of yeast are frequently joined together in clusters; in the yeast occurring in Demerara the cells are in the great majority of cases single; occasionally two cells and less frequently three are seen joined together. The races of yeasts which are known to exist are

divided, amongst other divisions, into two great classes:—Wild yeasts and cultivated yeasts.

A yeast is said to be a cultivated variety when it has passed through countless generations in conditions favourable to its growth; such a yeast may be a mixture of two or more varieties, or may consist solely of one particular race. A wild yeast is one which has not been systematically cultivated and finds its way into a fermentation process by adventitious means. Examples of cultivated yeast are found in the breweries in Europe, where the surplus yeast from one operation is used to perform the fermentation process in the next; the fermentation of grape juice is performed by a wild yeast which is found on the surface of the grape and many other fruits. It is stated by Deschamps that the greyish powder observed near the nodes of the cane consists in part of wild yeast cells.

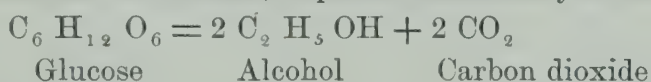
A very large number of different varieties of yeasts have been isolated in a pure condition and their properties studied, and at present it is the object of breweries and distilleries, worked on advanced lines, to perform the fermentation with a pure yeast of known properties. It has been shown by various investigators that certain yeasts of common occurrence produce in the fermentation disease in beer, either as an unpleasant taste or as turbidity, and in certain cases minute precautions are taken to prevent their presence: a yeast of known properties is grown originally from one single cell and cultivated in such a way as to prevent contamination until a sufficient supply is obtained to start the brewery or distillery; this yeast is passed on from fermentation to fermentation until on examination, it is found to be getting too impure, when a fresh start is made. For a description of this method Jorgensen's *Micro-organisms of Fermentation* should be consulted.

The differences in properties shown by different yeasts are chiefly in rate of fermentation, quantity of alcohol produced, flavour of product, and quantity of yeast formed, all of which are of great technical importance and are referred to later.

For alcoholic fermentation to take place two conditions are necessary; firstly, suitable nutrient solution, *e.g.*, one containing sugar, nitrogen, and various mineral matters, the constituents of the ash of yeast, of which are present potash, lime, magnesia, sulphuric and phosphoric acids, and secondly, a suitable temperature. In Europe yeast grows and performs alcoholic fermentations best at temperatures.

lying between 20° C. and 30° C.; below or above these figures the activity of the yeast is small, and between them is one temperature at which the maximum activity is shown, known as the *optimum temperature*. Below a temperature of 20° C. the activity of yeast falls rapidly until it ceases to exert its functions, but the organism is not destroyed in any way; at temperatures above 30° C. the activity likewise decreases and prolonged exposure results in destruction of the organism. In tropical countries the temperature at which the indigenous yeasts thrive is considerably higher and averages from 25° C. to 40° C., the yeast being practically inactive at 20° C.

The action of yeast during fermentation is two-fold; the organism secretes a product known as an enzyme or unorganised ferment which possesses the property of inverting cane sugar into dextrose and levulose; the two latter provide food for the yeast which splits them up into alcohol and carbon dioxide; expressed chemically the action is



According to this equation, 1 lb. glucose or .95 lb. cane sugar gives .511 lb. alcohol and .489 lb. carbon dioxide; in no case, however, is this result obtained in practice. Other bodies, notably higher alcohols, succinic acid, fatty acids, and furfural are formed; the presence of other ferments working conjointly with the yeast in practice also diminishes the yield of alcohol.

Before going on to describe the process of fermentation as carried out in practice, one other point may be mentioned: the vital energy of yeast can be directed to two ends, namely, cell reproduction and alcohol formation. A fermentation carried out at a high temperature results in a large yield of alcohol and small cell production, the greater part of the cells formed during the process dying; in distilleries, where quantity of spirit is aimed at, a high temperature process is carried on, although, as shown later, in certain tropical countries the reverse happens; in breweries generally, where the amount of alcohol produced is not of importance, a low temperature fermentation obtained when necessary by cold water circulation is used; in this case the yeast exerts a large part of its energy in cell reproduction, the yeast does not die and a large amount is collected for sale as *pressed yeast*.

The processes under which alcohol is manufactured may be classed under two headings; those in which yeast is added to the fermentable

liquid and those in which its presence is adventitious; to the former class belong the manufacture of beer, of whisky and most spirits, to the latter wine and rum. The manufacture of spirits as they are carried on in most European distilleries is as under. The basis of manufacture is grain; this is ground to a coarse powder and a weighed amount is placed in a digester mixed with water and heated by steam under a pressure of two or three atmospheres for an hour or more; the liquid contents of the digester are then blown into a second vessel and cooled; as soon as the temperature falls below 63°C , a proportion of malt is added; the malt contains a ferment diastase which converts the starch in the grain to a sugar, maltose; after the starch has been converted into maltose, the contents of the vat are drawn off into a fermenting vat and rapidly cooled; the vats are usually large enough to hold a whole day's work, and a distillery will have generally six fermenting vats, each of which may be of as great a capacity as 50,000 gallons. After the vat is set up it is '*pitched*' with yeast, and the temperature and quantity of yeast regulated with the object of obtaining the maximum yield of alcohol within the legal limit of time, *i.e.*, 72 hours. The temperature is regulated by means of water circulation through coils and maintained at 20°C — 25°C ; the high temperature promotes a rapid fermentation, but more fusil oils are formed than at a low one.

The preparation of the pitching yeast is as under:—A mixture of green malt and water is warmed to about 70°C ., kept at this temperature for about two hours to allow the starch to be converted to maltose and "*soured*." Green malt contains enormous numbers of bacteria, amongst which are the lactic and butyric acid organisms; butyric acid is a virulent yeast poison, and its development would injure the yeast; these organisms cannot be killed by raising the temperature as this would also destroy the action of the diastase. The butyric acid bacteria are, however, themselves susceptible to slight degrees of acidity; in order to destroy them without injuring the yeast the temperature is arranged so that the lactic acid bacteria can develop; the optimum temperature of the lactic acid bacteria is from 47°C . to 50°C ., that of the butyric acid organisms about 40°C . The mash is hence kept at a temperature of about 50°C ., whereby the lactic acid bacteria thrive and the formation of lactic acid effectually prevents the development of the butyric acid organisms. When the acid present reaches 1.0% to 1.1%, the process is stopped by raising the temperature to 70°C .; the mash is re-cooled to 20°C . and pitched

with yeast, in the proportion of about 1 lb. to 10 gallons; after about 14-16 hours the yeast has so far developed as to be used in the main process, a portion being kept for the next sour mash.

This process left much to chance, and has been developed on other lines although the object in view has always been the same. In the first place the presence of lactic acid bacteria is adventitious, and although their presence is very general it not infrequently happened that the process miscarried by reason of their absence; to get over this difficulty the infection of the sour mash was carried out by inoculation with pure cultures of lactic acid bacteria, and now more recently a new process known as the hydrofluoric acid process has been largely introduced.

It was sought for a long time to find some substance that would be antiseptic to the butyric acid bacteria and yet harmless to the development of yeast, and after many bodies had been tried Effront in 1890 introduced the use of alkaline fluorides. The initial proposition was to add from 4 to 8 grams of hydrofluoric acid per hectolitre (say from $\frac{1}{20}$ — $\frac{1}{10}$ lb. per 100 gallons) of the yeast mash which had been treated in the way described above, this quantity being found sufficient to prevent the development of injurious organisms. It was found, however, that this had often a bad effect on the yeast, and the next step was to acclimatise yeast to the presence of fluorides before using it in the actual process; and the method now carried out is as follows:—The yeast mash is taken direct from the principal mash and to it is added hydrofluoric acid or an alkaline fluoride in the proportion of about 1 oz. to 60 gallons, and then pitched with yeast; the yeast used is a pure culture yeast which has been acclimatised to the presence of fluorides; the heating of the mash to 70° C. and its maintenance at 50° C. as well as the addition of green malt are entirely dispensed with. Effront has also shown that the action of fluorides on yeast is two-fold, affecting both cell reproduction and fermentative energy; the presence of 3% ammonium fluoride arrests completely cell reproduction but merely reduces fermentative energy; by accustoming yeasts to the presence of fluorides, races of yeast are obtained which in the presence of about 2% of that acid have their decomposing energy stimulated and their cell reproductive power diminished, this leading to a larger production of alcohol.

The process followed in the manufacture of rum in Demerara is simple compared with the above; in the first instance there is no

necessity for the somewhat complicated method of extraction of fermentable malt from grain, and secondly no attempt is made to prepare yeast. Final or other molasses are mixed with water to an arbitrary density; this mixture may take place by hand but is much more effectually done in a mixer; such a mixer consists of a cylindrical vessel preferably of metal (the shell of a condemned multitubular boiler set on ends serves admirably); in this are fixed horizontally a series of blades; a vertical shaft carrying a bevel wheel is fixed on the central axis of the mixer; on the shaft are fixed a number of horizontal blades; the motion may be transmitted to the shaft by belt gearing, power being obtained from one of the distillery engines. A thorough agitation of the wash is very beneficial, as by its means the wash becomes thoroughly aërated. A good supply of oxygen is necessary for the good growth of yeast in its earlier stages, and mechanical agitation is more efficient than hand. In some distilleries in Europe it is customary to “*rouse*” the wash for some time after it is set up, *i.e.*, to keep the wash continually in agitation, and thus bring fresh layers of liquid to the surface. The density of the wash after setting up is generally 1.060; one gallon of strong sulphuric acid and 10 lbs. of sulphate of ammonia are added per 1,000 gallons of wash. The addition of the sulphuric acid is for a two-fold reason; it assists the ferment of the yeast to invert the cane sugar present and at the same time retards the development of butyric acid and other bacteria; the addition of ammonia is for the object of giving food to the yeast and obtaining a rapid and vigorous fermentation. The attenuation varies, being dependent on the composition of the molasses, the purity of the water supply, the cleanliness in the distillery. An average attenuation of 1.015 when working with properly exhausted molasses is satisfactory; this attenuation will correspond to an expenditure of about 12 lbs. glucose per gallon of proof spirit.

There are many distilleries, however, which do not obtain an attenuation of lower than 1.025 and others which, working with a comparatively rich molasses and pure water supply, attenuate as low as 1.005. The temperature during fermentation rises on an average to 105° F. and occasionally as high as 110° F.; the time taken for a vat to attenuate is from 36 to 48 hours.

In Jamaica a somewhat different process is carried out; cane juice is freely used and the wash is set up partly with water and with lees resulting from a previous fermentation, and partly with

skimmings from the sugar house. In 100 parts of wash there are as a general rule 10 of molasses, 30 of skimmings, 25 to 30 of lees or dunder, and the rest is water; the density of the wash lies between the limits 1·070—1·090; sulphuric acid and ammonia salts are not added, and the fermentation which is very slow lasts from eight to ten days, and is essentially a low temperature process. In neither process is yeast added but its presence is left to chance; although yeast cells are present on the rind of the cane it is only in cases where fresh cane juice is used as a source of alcohol that the fermentation is due to these cells, and generally at the beginning of distillery operations the fermentation is due to yeast that has fallen in from the air. Afterwards when the vats have passed through one fermentation, however carefully they may be cleaned, countless yeast cells will remain and subsequent fermentations are controlled by their presence.

The addition of lees or dunder from a previous fermentation is quite a rational process. Yeast cells are an exceedingly nitrogenous material, and on boiling, a portion of the nitrogen is rendered soluble, so that the lees or dunder contain more soluble nitrogen than the original wash; by the return of a portion of the lees a considerable amount of yeast food is provided.

In Mauritius a more complicated process is used; a barrel of about 50 gallons capacity is partly filled with molasses and water of density 1·10 and allowed to spontaneously ferment; sometimes a handful of oats or rice is placed in this preliminary fermentation. When attenuation is nearly complete, more molasses are added until the contents of the cask are again of density 1·10 and again allowed to ferment. This process is repeated a third time; the contents of the barrel are then distributed between three or four tanks holding each about 500 gallons of wash of density 1·10 and twelve hours after fermentation has started here, one of these is used to pitch a tank of about 8,000 gallons capacity; a few gallons are left in the pitching tanks which are again filled up with wash of density 1·1 and the process repeated until the attenuations fall off, when a fresh start is made. This process is very similar to what obtains in modern distilleries save that the initial fermentation is adventitious.

In Java and the East generally, a very different procedure is followed. In the first place a material known as Java or Chinese yeast is prepared from native formulæ; in Java, pieces of sugar cane

are crushed along with certain aromatic herbs, amongst which galanga and garlic are always present, and the resulting extract made into a paste with rice meal; the paste is formed into strips, allowed to dry in the sun and then macerated with water and lemon juice; the pulpy mass obtained after standing for three days is separated from the water and made into small balls, rolled in rice straw and allowed to dry; these balls are known as *Raggi* or Java yeast. In the next step rice is boiled and spread out in a layer on plantain leaves and sprinkled over with *Raggi*, then packed in earthenware pots and left to stand for two days, at the end of which period the rice is converted into a semi-liquid mass; this material is termed *Tapej* and is used to excite fermentation in molasses wash. The wash is set up at a density of 25° Balling and afterwards the process is as usual. In this proceeding the starch in the rice is converted by means of certain micro-organisms *Chlamydomucor oryzae* into sugar and then forms a suitable habitat for the reproduction of yeasts which are probably present in the *Raggi* but may find their way into the *Tapej* from other sources. About 100 lbs. of rice are used to pitch 1,000 gallons of wash.

The systematic research work which has been done on European yeasts, following on the investigations of Hansen and Jorgensen, still remains to be initiated* as regards the tropical yeasts to which the production of rum is due. The writer prepared 14 pure cultures of yeasts of Demerara origin, chiefly with a view of isolating any one which gave more complete attenuations or any pleasant flavour to the product. After several cultivations all the cultures gave practically identical attenuations, nor was any peculiar flavour noticed as a property of any one culture; he, however, observed that the yeasts could be divided into two classes, one of which on agitation curdled and sank to the bottom of the fermenting flask, the other remaining in a fine state of division and not sinking till several hours after agitation.

The flavour of rums may be due to some inherent property of the race of yeast causing fermentation, and such a property is perfectly well recognised in Scotch and Irish whisky distilleries. A distiller who by accident produces a whisky of certain bouquet is always very chary of making any improvement in his fermenting house which, while increasing the yield of spirit, may cause the peculiar flavour to

* Since the above was written a fermentation research laboratory has been installed in Jamaica.

be lost; and a rum distillery which makes a high quality of spirit might easily suffer serious loss in value by changing the fermentation process with the view to increased recovery.

Some other fermentations of interest in the sugar house are here mentioned.

Lactic Acid Fermentation.—The importance of this fermentation in European distilleries has already been touched on. There are numerous species of bacteria that produce lactic acid in their economy; they occur principally in milk and on green malt; the production of lactic acid as a commercial product from beer wort has been proposed and its commercial production from molasses does not seem impossible.

Acetic Acid Fermentation.—In this process alcohol is converted into acetic acid; the manufacture of vinegar from wine lees proceeds under the influence of organisms known collectively as the acetic acid bacteria; three distinct species are known to occur in Europe. The process is one of oxidation and a plentiful supply of air is necessary. In the sugar house, this process appears if cane juice be allowed to collect in any part of the factory, such as corners and crevices in the mill bed, and is preceded by an alcoholic fermentation. The presence of acetic acid is of course very destructive to ironwork; by neglecting to wash the centrifugals the fermentation may also be set up there, thus rusting the baskets. In the distillery, if from any cause fermented wash has to be kept on hand for a few days, a smell of vinegar becomes noticeable; this is due to the fermentation of the alcohol already formed to acetic acid, and if fermented wash be kept a sufficiently long time all the alcohol will eventually disappear and be replaced by acetic acid; in any case during fermentation a little acetic acid is always formed.

Butyric Acid Fermentation.—The role played by the bacteria which produce butyric has already been mentioned; a large number of species grouped together as the butyric acid bacteria are known; their action is not altogether similar, but in all cases butyric acid is formed as a decomposition product of glucose.

Viscid Fermentation.—It is noticed that sometimes the wash in a rum distillery attenuates badly and becomes thick and slimy to the touch. Similar diseases are known in Europe; raw beet juice sometimes with great rapidity turns mucinous and viscid; in beer,

which in Europe is subject to this disease, several organisms causing the disease have been found. If wash which has become viscid be examined under a high power microscope it will be found to swarm with rod shaped bacilli; in case such a state of affairs occurs in a distillery all the fermentation vats should be scrupulously cleaned out with lime water and afterwards with sulphuric acid, and all possible sources of infection, pipes, gutters, &c., similarly treated. The disease is most likely to occur from neglect of cleanliness or from use of too little acid in the fermentation process.

Leuconostoc Mesenteroides.—This is an organism which is widely distributed, and seems to have a favourite habitat in sugar factories; it has also been reported in Java and Russia. Its properties are to convert molasses, masse-cuites and juices into gelatinous masses, at the same time inverting all the cane sugar; it has also been reported as the cause of choking pipes used for the conveyance of molasses. The organism is extremely resistant to ordinary methods of destruction; when it has appeared in beet sugar factories disinfection with a 1% solution of ammonium fluoride is recommended.

Nitric Fermentation of Molasses.—In beet sugar factories the after masse-cuites on storing sometimes show a nitric fermentation. A dense red cloud of vapour due to the presence of nitrogen dioxide is observed to hang over the masse-cuites; this is ascribed to decomposition of the potassium nitrate present under the influence of bacteria, but really very little is known on the subject. The writer is unaware of any similar phenomenon being observed in cane sugar factories.

Spontaneous Combustion of Molasses.—Molasses when stored have been known to become charred; such a case is mentioned by Crawley (*Jour. Am. Chem. Soc.*, 19, 238), and is supposed to be due to heat developed originally by organisms.

Frothing of Molasses.—The frothing and bubbling of stored masse-cuites and molasses may be due to fermentation decompositions or, as suggested by Geerligs, to the spontaneous decomposition of glucinic acid formed by the action of lime on glucose.

Raw Sugar.—The deterioration of raw sugar when stored or in transit may properly be attributed to bacterial agency; to prevent it

the sugar should be shipped or stored in as dry a state as possible. (R. Greig Smith, *International Sugar Journal*, Nos. 44 and 45.)

Rum, as shipped at a strength of 40 over proof, consists almost entirely of from 70% to 75% of alcohol and 25% to 30% of water. Caramel and other bodies derived from the burning of sugar are also present in the coloured rum. The products of fermentation present other than alcohol are higher alcohols, especially amyl alcohol (fusel oil), formaldehyde, furfural, methyl alcohol, some fatty acids as acetic, formic, butyric and capric acids, and, as the result of interaction between the alcohols and fatty acids, some ethereal salts such as ethyl acetate, butyrate, &c. These bodies exist in very small proportion, and some of them may be entirely absent; their presence with the exception of the ethereal salts is objectionable, and it is the object of the distillation process to remove them; to the amyl alcohol is usually attributed the after effects of over indulgence in inferior spirits. The fatty acids especially those of high molecular weight have repulsive odours; to butyric acid is due the smell of rancid butter, that of stale perspiration being due to capric acid.

When using the old forms of pot stills the formaldehyde and methyl alcohol having low boiling points pass over in the first runnings, the fatty acids and higher alcohols having higher boiling points pass over in the last runnings; between these comes over the main body of the distillate; the first and last runnings are collected separately and are called *feints* or *low wines*. In the continuous type of still the methyl alcohol and formaldehyde are found in the cold feints, the fatty acids in the hot feints; a complete separation is however impossible, and all these bodies are found in greater or less degree in the spirit, dependent on the care exercised by the distiller. The boiling points of the principal constituents of rum are in degrees Fahrenheit:—Alcohol 173°; methyl alcohol 145°; formic acid 216°; acetic acid 246°; butyric acid 315°; capric acid 380°; ethyl formate 129°; ethyl acetate 168°; ethyl butyrate 241°; ethyl caprate 322°; formaldehyde 70°. It will be seen that ethyl acetate and alcohol have nearly the same boiling point so that any ethyl acetate present in the fermented wash will be totally recovered with the rum; the other bodies will be present in less quantity as their boiling point is more remote from that of alcohol; the majority of these bodies are, however, volatile in steam and hence are present in the distillate in larger quantity than would be supposed from their boiling point.

The flavour of rum is due to the ethereal salts mentioned above and rums are often doctored by their addition. In Jamaica it is usual to place fruits, which naturally contain these bodies, such as mangoes, guavas, pine apples, in the wash or even to allow the spirit to flow over trays containing slices of these fruits; in other cases the artificially prepared ethereal salt is added to the rum after its arrival in Europe, but this is a method entailing considerable expense. The flavour of the best rum is believed to be due to the presence of ethyl butyrate; the Jamaica practice of fermenting large quantities of sour cane juice containing much acetic acid would lead to the conclusion that the flavour is due to ethyl acetate.

Stade (*Sugar Cane* 297), quotes analyses of rum from Jamaica, Cuba and British Guiana, which are summarised below:—

There were present, expressed as grams per 100 c.c.: fusel oils ·037 to ·141; ethyl formate ·008 to ·022; ethyl acetate ·092 to ·612; ethyl butyrate trace to ·103; ethyl caprate ·005 to ·027; formic acid ·003 to ·012; acetic acid ·047 to ·156; butyric acid trace to ·011; capric acid ·003 to ·012. The writer would add that the only difference between the Jamaica rums and the others was the larger amount of ethyl acetate in the former, the Jamaica rums containing on an average ·044 grams per 100 c.c. as against an average of ·029 for the others.

In consequence of an abortive prosecution for selling genuine Demerara rum as genuine rum, the composition of the former, mainly as regards the proportion of ethereal salts, was made the subject of an exhaustive enquiry by J. B. Harrison. He found the ethereal salts (esters) to vary from a minimum of 23·7 to a maximum of 141·6 parts per 100,000 of alcohol, with a mean proportion of 64·7. In addition, he found that rums distilled in continuous stills contained on an average 44·9 parts of ethereal salts per 100,000 of alcohol; those from vat stills containing 69·9 parts.

A complete analysis of Demerara rums, due to W. M. Miller (*Timehri*, 1890, p. 90), are given below:—

ANALYSES OF DEMERARA COLOURED RUM.

	PERCENTAGE BY VOLUME.								
	1	2	3	4	5	6	7	8	9
Alcohol	80.84	80.40	79.19	77.39	76.68	80.56	77.32	80.98	80.19
Higher alcohols "fusel oil" .. .	.8956	.7975	.4557	.5903	.6942	.6463	.3218	.9243	.1581
Ethyllic formate.. .. .	.0088	.0153	.0405	.0373	.0233	.0396	.0180	.0373	.0350
Ethyllic acetate	.0243	.0231	.1258	.1563	.0645	.1018	.0542	.0636	.1229
Ethyllic butyrate	.0101	.0334	.0499	.0510	.0115	.0302	.0165	.0186	.0661
Total acid (as acetic)	.148	.190	.196	.160	.196	.160	.166	.131	.136
Volatile acid (as acetic)	(.018)	(.018)	(.060)	(.024)	(.030)	(.016)	(.024)	(.021)	(.015)
Total solids (colour)	1.040	1.210	1.750	1.510	1.420	.990	.1750	.680	.1050
Potash (K ₂ O) absorbed by colour..	(.1974)	(.2128)	(.2820)	(.2162)	(.2968)	(.1795)	(.2256)	(.1955)	(.1974)

On the other hand, H. H. Cousins claims for Jamaica rums very large quantities of ethereal salts, stating that common clean rums contain from 200-300, high-class ordinary rums from 300-400, and the best flavoured rums from 1,100 parts and over of ethereal salts per 100,000 of alcohol.

Rum, when freshly distilled, has a sharp unpleasant smell which on maturing gradually passes away and is replaced by a fruity odour. The initial unpleasant smell is due to the presence of fatty acids; in time these re-act with the alcohol and form ethereal salts to which the pleasant smell is due; the conversion is never complete and eventually a point is reached where equilibrium between alcohol, fatty acid, ethereal salt and water obtains. In addition to the methods of doctoring rum given above, a fatty acid, especially butyric acid, is occasionally added in small quantities to the spirit, so that in time ethyl butyrate is formed. Various patents employing ozone, electricity, have been taken out for the artificial maturing of spirits, but the writer is unaware that any of them have been used commercially to any extent.

Faulty Rum.—By faulty rum is meant a spirit which on dilution with water becomes cloudy and throws down a deposit. The causes to which this behaviour are attributed are:—The presence of caramels soluble in strong and insoluble in dilute spirit; the presence of higher fatty acids, due to careless distillation, which are precipitated on dilution; the presence of terpenes extracted by the spirit from the casks; the presence of a micro-organism capable of life and reproduction in 75% alcohol; the latter view was brought forward by V. H. and L. Y. Veley (*The Micro-organism of Faulty Rum*, Oxford University Press), who named the supposed organism *Coleothrix Methystes* and stated that it is extremely resistant to ordinary methods of destruction, survives dessication, is air borne and both aërobic and anaërobic; in certain of their publications the organism is described as multiplying and living actively in 75% rum and in other places as merely surviving in spirit. The whole of the results of V. H. and L. Y. Veley have been challenged by Scard and Harrison (*Sugar Cane*, July, 1898; *International Sugar Journal*, No. 3), who were unable to obtain any of the effects noticed by the Veleys. They found, however, in Demerara rums remains of organisms similar to the one in question, and were of opinion that faultiness in rum was due to the first three causes mentioned above.

When rum samples have been kept in an imperfectly sealed bottle so that the spirit is free to evaporate the writer has frequently noticed a slimy mucinous growth appear; this on microscopic examination is found to be of a fungus character, and to be similar to that described by Veley as the cause of faulty rum. The writer has never observed it in strong spirit, but when the fungus growth was transferred *en masse* to 75% alcohol, the organisms were not killed but cultures could be obtained for over a year; the growth did not increase in size but remained suspended in the rum, which remained quite clear; when a drop of the original weak spirit containing the fungus was inoculated into sound clear rum, no change whatever took place; the writer thinks it quite possible that masses of the organism to the existence of which he gives credence, have found their way into casks and puncheons, and have thus been present and alive on arrival into England, but does not think they can be called the cause of faulty rum.

Distillation as a physical phenomena differs in no way from evaporation and is used in the laboratory and in practice to effect the separation of volatile liquids from solids, in solution in the liquid or otherwise, and in the case of liquids of different boiling points, to separate the one from the other.

A distillery consists of four separate buildings; the liquor loft containing the fermenting vats, the still house in which are placed the stills, the engine house and the rum store; to these in certain cases may be added the boiler house.

The choice of position for the liquor loft is not unimportant, as experience has shown that the fermentation is affected by apparently trivial causes; it should be raised on pillars about fifteen feet from the ground, be well lighted and ventilated and open on all sides to the breeze and should not be shadowed by the other factory buildings. In certain factories the rum store is built underneath the liquor loft; this is inadvisable as besides running the risk of wash leaking into the rum vats, circulation of air underneath the liquor loft is prevented. The pipes and gutters used in connection with the distillery should be placed and arranged so that they present easy access for cleaning; underground pipes, and concrete or brickwork tanks in connection with a distillery are to be unhesitatingly condemned.

The engine and boiler house should be placed on the lee side of the fermenting loft; if placed to windward the liquor loft runs a chance

of becoming over-heated. The engines used in connection with a distillery are mainly pumps; those of the Worthington pattern leave nothing to be desired; power is, however, required to work the mixer employed in mixing molasses and water. Where flywheel pumps are used power can be taken from these.

The number of vats and their capacity depends on the amount of molasses available and the time required for fermentation; every 100 gallons of molasses will give between 600 and 700 gallons of wash at a density of 1.060, and from every 100 tons of sugar made, from 6,000 to 9,000 gallons of molasses result, dependent of course on the composition of the juice. Given 100 tons of sugar per week, from 7,000 to 9,000 gallons of wash per day will be produced, and allowing the fermentation to take 48 hours, the capacity of the vats must be double this; in practice it would be advisable to allow at least 25% in excess of the calculated figure. Of course in many places a longer period than 48 hours is taken in the fermentation, and then a corresponding increase in the capacity of the vats must be allowed. A usual size of vat found in the West Indies is one holding about 3,000 gallons; in Scotch and English distilleries much larger vats are the rule and a capacity of 50,000 gallons is not unusual; the initial cost of erecting a few large vats and a loft to contain them and cost of upkeep, is less than for a larger number of small vats, and it is a general opinion that a slightly better fermentation is obtained in larger vats.

Antiseptics should find a larger use in distilleries, especially when shut down; all gutters, pipes, &c., should be carefully cleansed. The antiseptic most in use in Europe now is a 1% solution of ammonium fluoride; fresh milk of lime is, however, an efficient cleanser and it will be found sufficient if all vats and other places, which come in contact with sweets, be washed down on ceasing operation with milk of lime.

The stills used to extract spirit from the fermented wash may be divided into two classes, direct fired and steam stills, or again into intermittent or continuous stills. Direct fired stills are very uncommon and only a few remain in unprogressive districts; they are constructed of copper and set in brickwork over a furnace with a circular flue; besides being expensive as regards first cost they are very uneconomical in fuel consumption.

A sectional view of the general form of steam heated vat still is given in *Fig. 128*; *a* is a wooden vat of capacity varying with the amount of wash to be treated; at *d* is shown the pipe through which the lees are discharged when the wash is exhausted; steam from the boilers is admitted by the pipe *b*, which reaches nearly to the bottom of the vat; on the top of the vat is placed the copper goose neck *c*, which is continued into a smaller vat *e* known as the retort; in the latter are placed the low wines resulting from

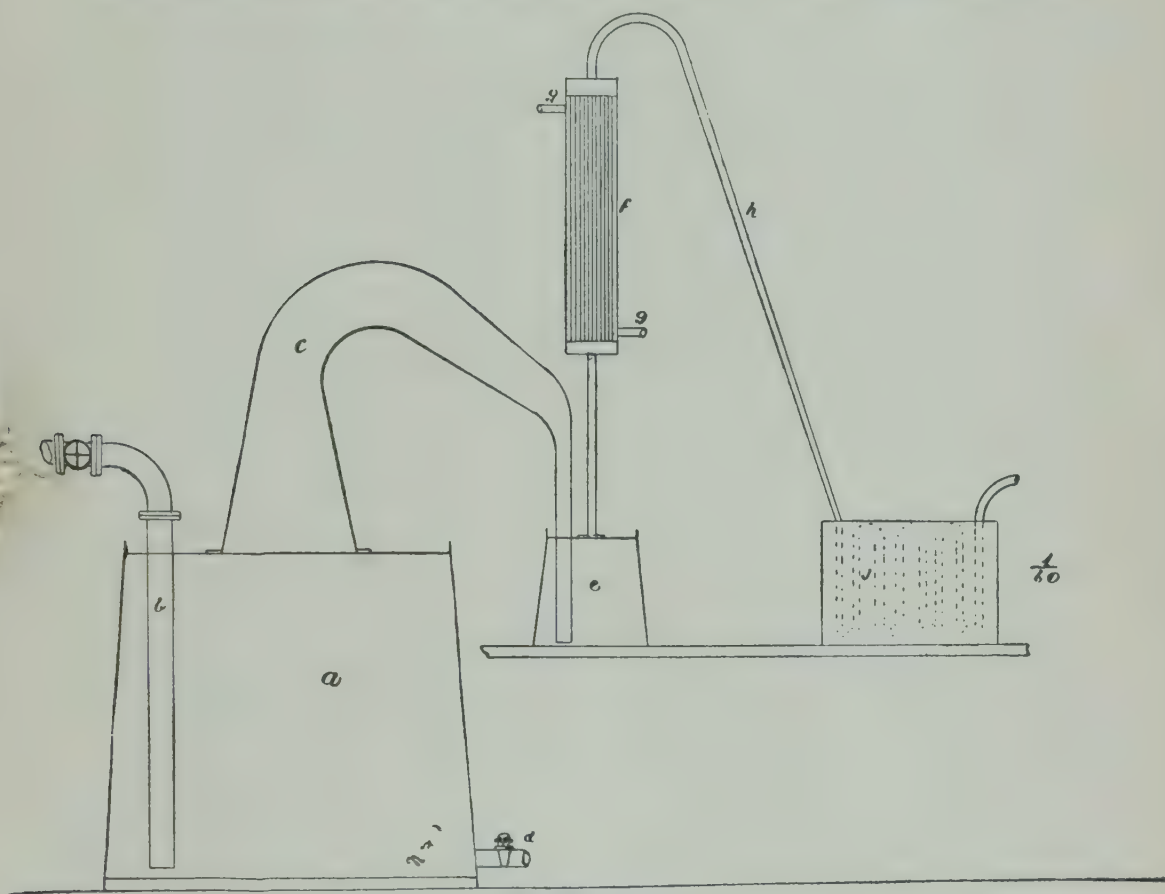


FIG. 128.

the previous operation. At *f* is shown the rectifier; this consists of an upright cylindrical copper vessel in which are fixed a large number of tubes of small diameter; water is admitted to the rectifier by the pipe *g* and circulates on the outside of these tubes; from the rectifier a pipe passes to the tank *j* in which a supply of cold water circulates, and after passing in a serpentine fashion emerges at *l* and passes on to the spirit receiver. The mixed watery vapour and alcohol proceeds from the still to the retort where it takes up any alcohol still remaining in the low wines, and passes upwards through the rectifier where a

large portion of the water and other bodies of high boiling point condense and fall back into the retort; the vapour of alcohol leaves the retort at a temperature of from 180°F. to 190°F. and is condensed in the serpentine in the tank *j*.

In *Fig. 129* is given a semi-diagrammatic view of what is known as the *French column* which is practically identical with *Coupiér's still*; the column or dephlegmator *a* is divided into chambers by plates,

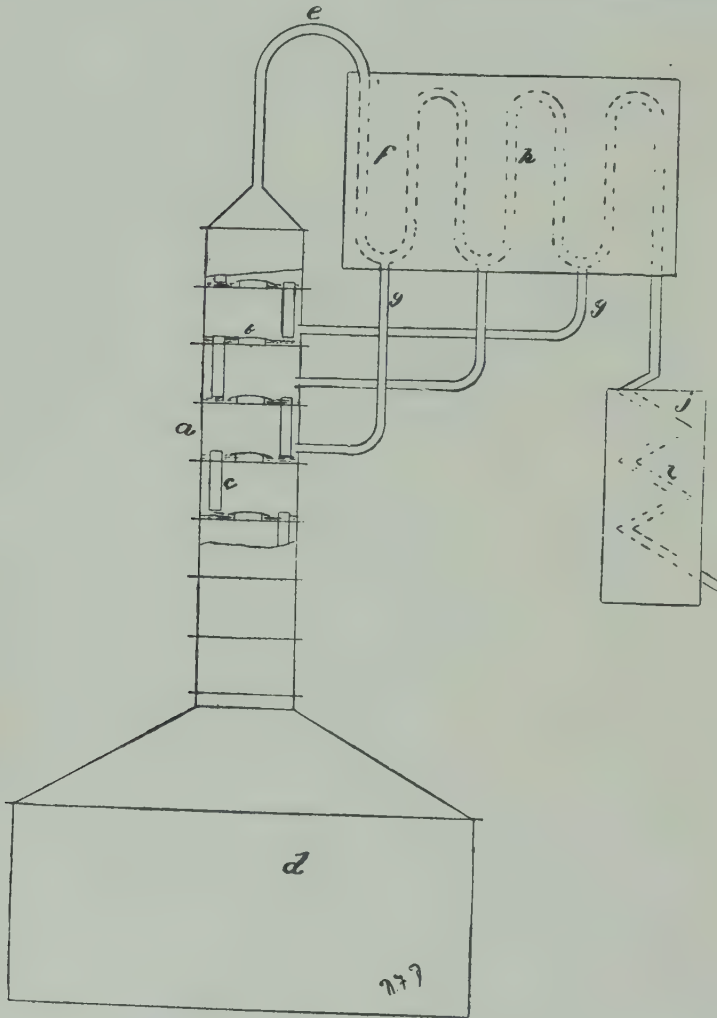


FIG. 129.

each of which has a central opening covered by a dome *b*; a small overflow pipe *c* passes from each plate to the next; the vapours from the boiler *d* pass upwards through the central openings through the layer of liquid on each plate, and thence through the overflow pipes back to the boiler; the vapours of high boiling point are condensed in the U pipes *h* in the condenser *f*, passing back to the still by the pipes *g*; a coil *i* is shown in the tank *j* where the spirit is cooled.

In *Fig. 130* is given a sectional view of the Coffey type of still ; it consists of two parts, the Analyzer A and the Rectifier R ; either

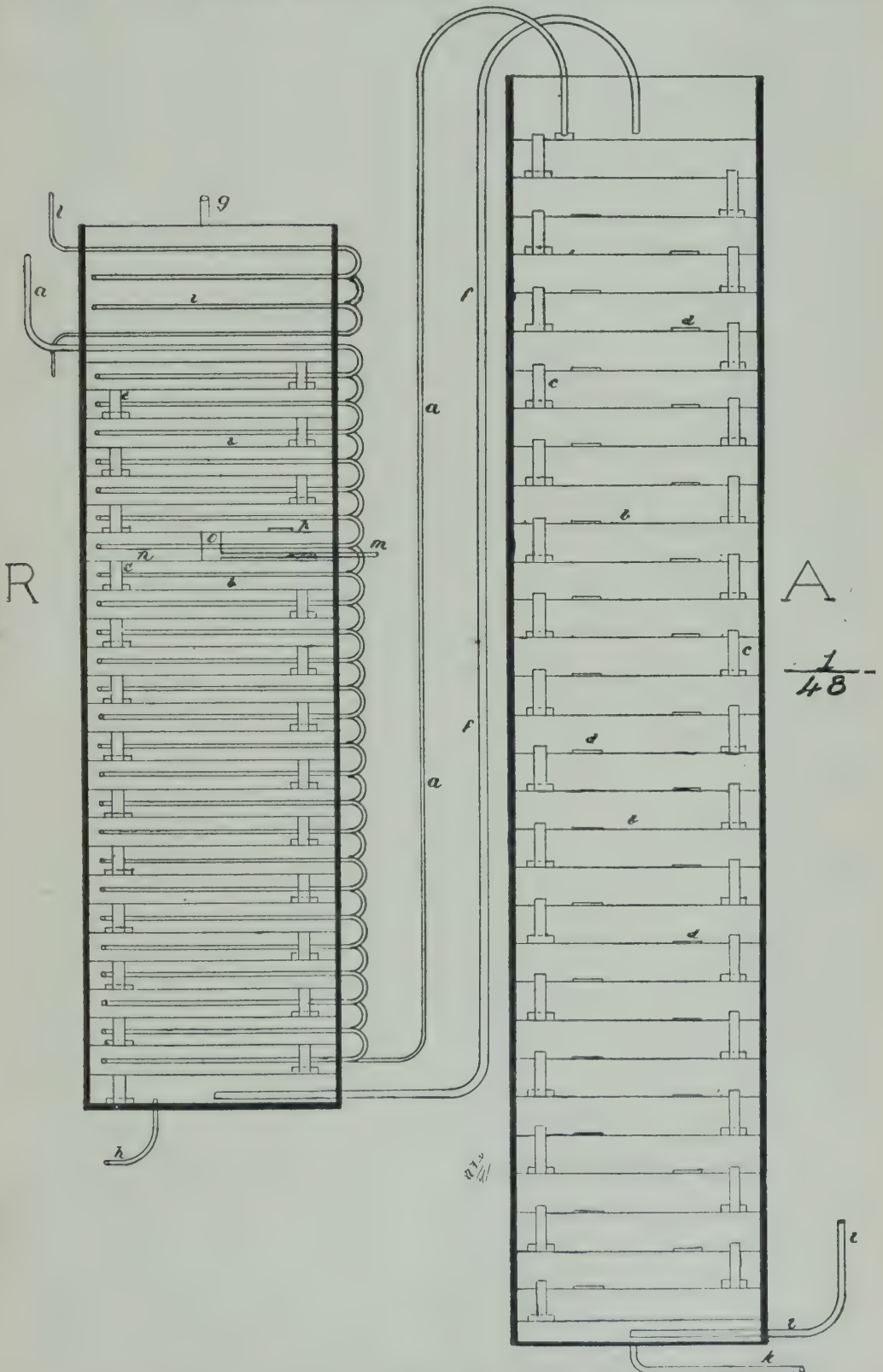


FIG. 130.

column is built up of rectangular wooden frames resting one on top of the other and the whole kept in position by a number of vertical stay rods. The analyzer is divided into a number of chambers formed by the interposition of copper plates *b b*, perforated with a large number of holes about $\frac{1}{8}$ in. diameter; in each plate is a disc valve *d d* consisting of a disc of copper about 3 in. diameter and opening upwards; from each plate passes down a dip pipe *c c* about 9 in. long and 3 in. diameter; the top of the dip pipe projects about 1 in. above the copper plate and dips into a cup which rests on the next lower plate. The rectifier is divided into chambers by similar diaphragms, save that the five upper chambers are separated from the others by an unperforated copper sheet *n n*, which has a large opening at *p* and a receptacle at *o* from which leads out a pipe *m*; the opening at *p* has a collar 1 in. high; the five upper plates have no valves or perforations, their object being to cause vapour to pass in a serpentine direction.

The method of working is as follows:—Wash is pumped into an overhead tank (not shown) and flows down the pipe *a a*; this pipe is continuous, and emerging at the bottom of the rectifier is carried to the top of the analyzer and discharges the wash over the top diaphragm; the wash flows down the analyzer in a zig-zag direction passing down the dip pipes, which are placed as shown at alternate ends of the plates; reaching the bottom of the analyzer the wash discharges through the pipe *k*. Steam is admitted at a pressure of from 5 to 10 lb. per square inch by the pipe *i i*, and passes upwards through the perforations in the plates; the cups in which the dip pipes stand are always full of wash, and acting as a seal prevent passage of vapour except through the perforations; the dip pipes projecting an inch above the diaphragms always keep this depth of liquid on the plates; in case the vapour is unable to pass quickly enough through the perforations, it can obtain a passage through the valves *d d*; the steam in its passage through the wash deprives it of its alcohol and a mixed vapour of alcohol, water and other volatile constituents, passes out of the analyzer by the pipe *f f*, and is led into the bottom of the rectifier; as the vapour meets the cold wash in the continuous pipe *a a*, it is condensed and at the same time heats the wash; the water vapour and bodies of high boiling point, as well as some alcohol, are condensed in the lower part of the still and fall down to the bottom and are continually taken away by the pipe *h*, called the hot feints pipe. The alcohol in great part condenses in the upper five chambers and falling down on the plate *n n*, is received in the

receptacle *o* and taken away by the pipe *m*; this pipe leads to a refrigerator and thence to the spirit store. A pipe *g* leads from the top of the rectifier and takes away the uncondensed vapour; this pipe too passes through a refrigerator, and the condensed vapours are collected and form the cold feints; *ll* is a water coil, by means of which the amount of cold feints allowed to be formed can be regulated. The hot feints can either be allowed to mix with the wash or they may be passed through a condenser and pumped to the top of the analyzer. The cold feints are collected separately, and when sufficient have accumulated, they are mixed with the wash and redistilled; if pumped directly to the analyzer, owing to their low boiling point they volatilize with explosive violence.

The wash leaves the rectifier at a temperature of about 190°F . and is completely exhausted of spirit in its passage down the diaphragms of the analyzer, the expelled vapour passing through the pipe *ff* being at a temperature of about 205°F . to 210°F . The upper coil in the pipe *aa* is at the temperature of the wash, and the temperature increases regularly on passing down; the strength of spirit condensed in the upper five chambers can be regulated by controlling the temperature. A high temperature causes alcohol to pass off in the cold feint pipes, and at the same time diminishes the condensation of watery vapour so that a weak spirit results; a low temperature makes alcohol condense below the spirit plate, increasing the quantity of hot feints. To obtain the best results the temperature of condensed spirit in the spirit plate should lie between 176°F . and 180°F . The control of the still is effected either by regulating the supply of wash or of steam; valves are fitted, of course, on both the wash pipe and steam pipe. To enable the attendant to know the strength of the spirit at any moment, a small pipe passing through a supplementary refrigerator takes a sample of spirit from the spirit plate and conducts it to a locked test case; if spirit 45 O. P. is required, three glass bubbles, one which floats in 42 O. P., one in 45 O. P. and one in 48 O. P. are placed in the vessel receiving the spirit; as soon as all three bubbles rise the attendant knows his spirit is too weak, and when two sink that it is too strong. As a further guide thermometers are placed in various parts of the still; one in the spirit plate, a second at about the twelfth coil of the rectifier, and a third on the pipe carrying wash to the analyzer.

To use these stills to greatest advantage they must be worked with as little sudden change as possible; control is effected by regulating

either the flow of wash or steam ; in forms of stills where the wash is pumped to an overhead tank, opening or shutting a cock or valve (the latter preferably) controls the flow of wash. In other forms where the wash is pumped directly through the coil a cock is fitted on the pipe, convenient to the distiller, and connected to a second pipe leading back to the vessel from which the pump draws. The amount of steam is regulated by a valve ; in general it is preferable to control working by the flow of wash.

The spirit should not be run from the spirit plate too rapidly ; if the latter be emptied by opening the cock too much, a weak spirit collects and the cock must be closed until the test bubbles show that spirit of the correct strength is forming. The supply of wash and steam must be adjusted to each other ; too little steam imperfectly exhausts the wash and an excess results in too much watery vapour passing over, giving a weak spirit. To allow the distiller to see that the wash is properly exhausted, vapour from the lees is collected in a separator, and carried through the supplementary refrigerator to a test glass in which are bubbles floating in water and spirit 98 U. P. ; should either of these sink it is certain that the wash is imperfectly exhausted. The advantage of these stills over the common type of vat still lies chiefly in their economy of steam ; a comparison of heat used in both cases is given below. In the case of the ordinary vat still, the minimum quantity of heat required is per 1,000 gallons distilled, raising wash from 90° F. to 210° F.

$10,000 \times .9 \times (210-90) = 1,080,000$ B.T.U.

the specific heat of wash being taken at .9.

Evaporating 45 gallons of alcohol

$$450 \times .8 \times 457 = 174,520 \text{ B.T.U.}$$

Evaporating 20 gallons of water

$$200 \times 966 = 193,200 \text{ B.T.U.}$$

$$\text{Total} \quad \dots \quad \dots \quad \underline{1,447,720}$$

In the case of the Coffey still the condensation of the evaporated spirit and water heats the wash to a temperature of about 190° F, so that it has only to be further heated by steam from 190° F. to 210° F. and requires

$$10,000 \times .9 \times (210-190) = 180,000 \text{ B.T.U.}$$

The other heat consumption is the same as above, so that the total in this case is 547,720.

Hence the continuous still requires about one-third of the steam taken by an intermittent vat still ; in addition the wash is under the

action of steam for a very much shorter time, and the heat required to maintain the wash at the high temperature is not so great. In the above calculation the specific heat of wash is taken as 0.9, and the wash is supposed to give a return of 6.5% strong spirit consisting of 4.5% by volume of alcohol and 2.0% of water, and the specific gravity of alcohol is approximated at 0.8.

Approximate dimensions of a continuous still of the Coffey type working up 1,000 gallons of wash per hour are here given, the letters referring to sketch in Fig. 130. Rectifier R, total height 24 ft. $\times$ 8 ft. $\times$ 3 ft.; Analyzer A, total height 42 ft. $\times$ 8 ft. $\times$ 3 ft.; number of chambers in both analyzer and rectifier 27; total length of pipe *a a*—contained in analyzer—416 ft.; diameter of pipe 2 in.; total surface of pipe 217 square feet; size of dip pipes *c* in rectifier 4 in. $\times$ 9 in.; and in analyzer 13 in. $\times$ 3 in.; diameter of valves *d* 5 in.; diameter of vapour pipe *f* 7 in.; diameter of steam pipe *i* 4 in.; diameter of hot feints pipes *h* 1½ in.; diameter of spirit pipe 1½ in.; diameter of cold feints pipe 6 in. The still described is one constituted of wood and is of rectangular section; other forms of stills are built throughout of copper and are often of circular section, the wash pipe being worm shaped instead of straight with U bends as in this case.

Some miscellaneous data of use in distillery work may be given here.

One pound glucose could at most give 1.269 lbs. proof spirit or .1396 gallon at 84° F.

One pound sugar could at most give 1.276 lbs. proof spirit or .1414 gallon at 84° F.

One gallon proof spirit at 84° F. could be made from 7.17 lbs. glucose or 7.07 lbs. cane sugar.

One pound cane sugar on inversion gives 1.0526 lbs. glucose.

In general practice from 10 to 13 lbs. glucose are required to make one gallon proof spirit.

Density of proof spirit at 84° F., .9091.

A gallon of rum or a gallon and a half of proof spirit from one gallon of exhausted molasses is exceptionally good working, a gallon of rum per gallon molasses being fair average working; expressed as percentages of the maximum possible yield a recovery of 80% or more is excellent, of 70% to 75% is fair average working and below 70% is bad.

The manufacture of caramel as a colouring agent for rums forming an integral part of distillery work is discussed below.

Caramel is the name given to the decomposition products obtained

on heating sugar or glucose to temperatures in the neighbourhood of $180^{\circ}\text{C}.$; a black brittle amorphous highly hygroscopic substance, which reduces Fehling's solution, results. This body is certainly a mixture of various bodies, of the chemistry of which nothing is known. The product when prepared from pure sugar or glucose, and when care is taken to prevent local superheating, is highly soluble in water and to a less degree in spirit; there are present, however, especially when the decomposition is pushed to extremes, caramels which are insoluble in water and soluble in spirit. If these are present in any notable quantity, a perfectly clear 40 O.P. spirit may give a deposit when mixed with water and to the presence of these caramels is to be attributed one of the causes of faultiness in rum.

Caramel produced by burning sugar is completely soluble in water in the presence of alkalies, and the solution at the same time assumes a much darker colour; but caramels dissolved in spirit are precipitated by alkalies, the solution becoming less coloured; in the presence of alkalies the flavour of the caramel undergoes a complete change, and at the same time gives off a peculiar odour.

A process which was long kept a trade secret, and extensively used, especially for colouring rums, consisted in burning sugar in the presence of alkalies; the proportions used were 60 parts of sugar and 2 parts of sodium carbonate or 1.5 parts of caustic soda. This process is referred to as Asrymusry's; in view of what has been said above on the action of alkalies on caramel dissolved in spirit, this process would hardly promise success. The temperature at which the conversion of sugar into caramel takes place has been stated by different authorities as between $160^{\circ}\text{C}.$ and $250^{\circ}\text{C}.$

When caramel is used for colouring rum, two points have to be considered; the caramel should reduce the strength of the spirit as little as possible, and give to the rum a sugary flavour. To obtain the latter effect the molasses or sugar syrup should not be burned too far, but in this case the amount of caramel required to give the necessary depth of colour so much increases the density of the spirit that there is a large apparent loss.

The usual method of preparing caramel is as under:—Into an iron pot of about 200 gallons capacity, usually an old iron tayche, are introduced 40 to 50 gallons of molasses, and water added to a density of about 1.25; instead of molasses a syrup of sugar and water of the same density is sometimes used. A brick oven is built under the pot, and a brisk fire kept up; the molasses or syrup must

be kept in continual motion, preferably by a mechanical stirrer. The sugar solution rapidly darkens, and in from 60 to 90 minutes is quite black. The usual test to show if the caramel is sufficiently burned is to remove a portion on a stick, and after cooling, to break the caramel with the finger; it should be quite brittle. Another test is to drop a globule of the burnt caramel into water, the floating of the globule being an indication that the caramel is sufficiently burned; when either of these tests obtains, the caramel will colour rum reasonably well, but to obtain a low *obscuration* the burning must be continued longer. When the point at which the caramel is sufficiently burned is decided, the fire is drawn and sufficient water added to permit of easy carriage to the rum store.

The higher the temperature at which the caramel is burned, the less is required to produce the necessary depth of colour, and the apparent loss of strength is lower; the after treatment in the rum store has also an effect on the caramel. If the crude colour be repeatedly treated with strong 60 O.P. to 70 O.P. spirit, the colour solution allowed to settle, and the clear colour drawn off, eventually a colour is obtained which gives a barely appreciable *obscuration*; this process is too lengthy to carry out in practice, but a colour burnt as described above and treated once, bulk for bulk, with white rum from the still, will give a fully coloured rum with apparent strength, as shown by the Sikes hydrometer, only from one to two proof degrees less than the actual.

In the West Indies first molasses are generally used to prepare caramel, and one gallon of molasses should afford material sufficient to colour from 50 to 60 gallons of rum.

It is sometimes found that a coloured rum obstinately refuses to settle; in this case the addition of about four ounces of alum per 1000 gallons of spirits will often be found beneficial.

The essential part of the analysis of a caramel is the determination of its colour intensity; this determination is usually made by dissolving a fixed weight of caramel in a definite volume of water or spirit and comparing the colour with a standard prepared under similar conditions, or the colour may be matched in terms of Lovibond's tintometer, which forms a very useful instrument for this purpose. Determinations of the ash and reducing power are also sometimes made; a molasses caramel of course carries more ash than a sugar caramel. The copper oxide reducing power varies considerably and generally lies between .3 and .6, that of glucose being unit; for highly burnt molasses caramel the writer has found a reducing power of about .5. Connected

inversely with the colour intensity is the obscuration, caramel of high colour intensity giving a low obscuration.

In the preparation of caramels for beers, porters and vinegars, a very well-known trade formula is the addition of salts of ammonia, chiefly the carbonate and chloride, in quantities of one to two pounds per 100 lbs. of sugar or glucose; their addition is said to increase the colour intensity and to modify the harsh bitter taste.

Various patented caramels are on the market; these consist essentially of organic dyes and are not caramels at all; they colour rum with a low obscuration but spoil the flavour and do not keep their colour permanently; their use is not to be recommended. Logwood extract has also been used as a source of colour for rum.

The obscuration of a spirit is the difference between the actual proof strength and the apparent proof strength as determined by an immersion alcoholometer. Thus spirit showing 40·0 over proof by the alcoholometer, and of actual strength 43·1 over proof is said to have an obscuration of 3·1; in some cases, however, the obscuration is expressed on the proof spirit, so that for the example quoted the obscuration is $\frac{3\cdot1}{1\cdot431} = 2\cdot17$ per cent. on proof spirit.

The easiest method of determining the obscuration is as under:—

1. Take the apparent strength by the hydrometer.
2. Evaporate about 200 c.c. of the spirit on a water bath till all the alcohol is removed; take up the residue with water, and make up to the volume of the spirit taken.
3. Take the density of the solution of the residue either by the pycnometer or by a hydrometer graduated to read ·0001. It is absolutely essential that all measurements be made at that temperature at which the instruments are graduated.

Calculation: Let x = specific gravity of the obscured spirit, and d = specific gravity of the residue dissolved in water; then $\frac{x}{d}$ = original gravity of the spirit.

Example: Coloured rum stands 21·0 Sikes at 84° F., indicating an apparent strength of 40·6 O.P.; the specific gravity corresponding to 21 Sikes is ·8512. The density of the residue dissolved in water is 1·0040. Then original gravity of spirit = $\frac{\cdot8512}{1\cdot0040} = \cdot8478$. The Sikes indication corresponding to a specific gravity of ·8478 is 19·0, indicating a spirit 42·8 O.P.; hence the obscuration is $42\cdot8 - 40\cdot6 = 2\cdot2$.

An older formula for use with this method gives $x - d$ = original gravity of the spirit.

A second method, and one generally used for beers and wines, consists of distilling over the material until all the alcohol has passed over, making the distillate up to the original volume and finding the strength of the distillate by an immersion alcoholometer, which in the absence of solids in solution gives exact results; with strong spirit, such as rum, it is extremely difficult, if not impossible, to prevent loss by evaporation and the first method is preferable.

In the following table are calculated obscurations from the observed density of the residue dissolved in water, the standards adopted for the calculation being a spirit of strength 40·6 O.P. (= 21·0° Sikes) at a temperature of 84° F.; the table is applicable to spirits varying considerably from these adopted standards.

The methods adopted for the laboratory control of the distillery are briefly detailed below:

Density.—The density of the wash when freshly set up and after complete fermentation is taken with an ordinary immersion hydrometer; a Balling instrument, such as is used in sugar house work, is suitable; in distillery work it is usual to note the actual density and not the degree Balling. The wash, when finally fermented, is usually of temperature 105° F. or so, and the sample should be allowed to cool before making the observation.

OBSCURATION TABLE.

Density of dissolved Residue.	Obscuration.	Density of dissolved Residue.	Obscuration.	Density of dissolved Residue.	Obscuration.
1·0000	0·0	1·0028	1·5	1·0054	2·9
1·0002	0·2	1·0030	1·7	1·0056	3·0
1·0004	0·3	1·0032	1·8	1·0058	3·1
1·0006	0·4	1·0034	1·9	1·0060	3·1
1·0008	0·5	1·0036	2·0	1·0062	3·2
1·0010	0·6	1·0038	2·1	1·0064	3·3
1·0012	0·7	1·0040	2·2	1·0066	3·4
1·0014	0·8	1·0042	2·3	1·0068	3·5
1·0016	0·9	1·0044	2·4	1·0070	3·6
1·0018	1·0	1·0046	2·5	1·0072	3·7
1·0020	1·1	1·0048	2·6	1·0074	3·7
1·0022	1·2	1·0050	2·7	1·0076	3·8
1·0024	1·3	1·0052	2·8	1·0078	3·9
1·0026	1·4				

Attenuation.—The attenuation is the difference between the initial and final density, water being put equal to 1,000; thus, wash initially at 1,063 and finally at 1,015 is said to have attenuated 48 degrees. For each degree of attenuation it is customary to assume the presence of so much proof spirit; a common allowance is 1% of proof spirit for each 5 degrees of attenuation. As the result of a series of laboratory fermentations with pure cultures, the writer found 1.17% of proof spirit for every 5 degrees of attenuation. This method is not meant as an accurate determination of percentage of proof spirit, but as a guide to revenue and customs authorities.

Fermentable Matter.—As the sugar present in wash must be inverted before fermentation takes place, its determination as such is quite unnecessary. The routine followed by the writer is as follows:—To 10 c.c. of wash is added one c.c. of basic lead acetate, sufficient acetic acid to render the wash acid, after which the excess of lead is precipitated with sulphate of soda. The whole is then made up to 100 c.c. and filtered. 50 c.c. of the filtrate are inverted as described under Clerget's method, neutralised and made up to 100 c.c. An approximately half per cent. solution of glucose is thus obtained, in which the glucose is determined as already indicated. As the greater part of the glucose is invert sugar, tables based on a dextrose basis should be corrected by adding 3 per cent. to the values so found.

The wash after fermentation is generally found to reduce Fehling's solution, and it is uncertain if the reducing power is due to fermentable or to unfermentable matter. In English distilleries it is customary to deduct the body or bodies found after fermentation, expressed as glucose, from the total amount found before fermentation, the body so found being termed *gallisin*.

Alcohol in Fermented Wash.—Distil 100 c.c. or any convenient quantity till two-thirds of the volume has come over; make up to the original volume and determine the percentage of alcohol with an alcoholometer, or more accurately by means of a pycnometer. A table connecting the density of dilute aqueous alcohol and density is given below as well as one connecting the degree Sikes and density at 84° F.

Alcohol in Lees.—The lees discharged from the still should be tested occasionally for alcohol; this is readily done by distilling over some lees and comparing the density with water. If anything but a trace of alcohol is found, it should be determined as above.

DEGREE SIKES AND SPECIFIC GRAVITY AT 84° F.

	0	·1	·2	·3	·4	·5	·6	·7	·8	·9
17	·8443	·8444	·8446	·8448	·8450	·8452	·8453	·8455	·8457	·8458
18	·8460	·8462	·8464	·8465	·8467	·8469	·8471	·8472	·8474	·8476
19	·8478	·8479	·8481	·8483	·8485	·8487	·8488	·8490	·8492	·8493
20	·8495	·8497	·8498	·8500	·8502	·8503	·8505	·8507	·8509	·8510
21	·8512	·8514	·8516	·8518	·8519	·8521	·8523	·8524	·8526	·8528
22	·8530	·8531	·8533	·8535	·8537	·8538	·8540	·8542	·8544	·8546

Analyses of the nitrogen and ash of the wash can be made as described under juice; such analyses may be required to determine if there is a sufficiency of nutriment for the yeast, and also in estimating the manurial value of spent wash. The methods used in plant ash analyses are available.

The table on the next page, connecting specific gravity and percentage of alcohol, is abbreviated from the one in use by the U. S. Board of Inland Revenue; the standard temperature used in the table is 15·6° C. = 60° F.; the expansion of water and dilute alcohol is so nearly the same as to allow the table to be used for a temperature of 84° F., the standard of density now being, water at 84° F. = unity. The percentage of proof spirit is obtained by multiplying the percentage of alcohol by 1·7525.

TABLE CONNECTING SPECIFIC GRAVITY AND PERCENTAGE OF ALCOHOL.

Specific Gravity.	Alcohol % by Volume.	Specific Gravity.	Alcohol % by Volume.	Specific Gravity.	Alcohol % by Volume.	Specific Gravity.	Alcohol % by Volume.	Specific Gravity.	Alcohol % by Volume.	Specific Gravity.	Alcohol % by Volume.	Specific Gravity.	Alcohol % by Volume.	Specific Gravity.	Alcohol % by Volume.	Specific Gravity.	Alcohol % by Volume.	Specific Gravity.	Alcohol % by Volume.
1.00000	0.00	0.99854	0.95	0.99716	1.90	0.99579	2.85	0.99445	3.80	0.99315	4.75	0.99189	5.70	0.99065	6.65	0.99947	7.60		
0.99992	.05	849	1.00	708	.95	571	.90	438	.85	308	.80	182	.75	059	.70	940	.65		
984	.10	842	.05	701	2.00	564	.95	431	.90	301	.85	175	.80	053	.75	934	.70		
976	.15	834	.10	694	.05	557	3.00	424	.95	295	.90	169	.85	047	.80	938	.75		
968	.20	827	.15	687	.10	550	.05	417	4.00	288	.95	162	.90	040	.85	922	.80		
961	.25	819	.20	679	.15	543	.10	410	.05	281	5.00	156	.95	034	.90	916	.85		
953	.30	812	.25	672	.20	536	.15	403	.10	274	.05	149	6.00	027	.95	909	.90		
945	.35	805	.30	665	.25	529	.20	397	.15	268	.10	143	.05	021	7.00	903	.95		
937	.40	797	.35	658	.30	523	.25	390	.20	261	.15	136	.10	015	.05	897	8.00		
930	.45	790	.40	651	.35	515	.30	383	.25	255	.20	130	.15	009	.10	891	.05		
920	.50	782	.45	643	.40	508	.35	376	.30	248	.25	123	.20	002	.15	885	.10		
915	.55	775	.50	636	.45	501	.40	369	.35	241	.30	117	.25	.98996	.20	879	.15		
907	.60	768	.55	629	.50	494	.45	363	.40	235	.35	111	.30	990	.25	873	.20		
900	.65	760	.60	622	.55	487	.50	356	.45	228	.40	104	.35	984	.30	867	.25		
892	.70	753	.65	615	.60	480	.55	349	.50	222	.45	098	.40	978	.35	861	.30		
884	.75	745	.70	607	.65	473	.60	342	.55	215	.50	091	.45	971	.40	855	.35		
877	.80	738	.75	600	.70	466	.65	335	.60	208	.55	085	.50	965	.45	849	.40		
869	.85	731	.80	593	.75	459	.70	329	.65	202	.60	079	.55	959	.50	843	.45		
861	.90	723	.85	586	.80	452	.75	322	.70	195	.65	072	.60	953	.55	837	.50		

APPENDIX.

ADDENDUM TO CHAPTER VI.

Since the chapter on the manuring of the cane was in type, Prof. J. B. Harrison has given (*West Indian Bulletin*, Vol. V., No. 6) a summary of the results derived from 24 years' experimental work in the British Guiana Botanical Gardens. A short abstract of these results of great interest to cane growers is given below:—

Lime.—Alternate beds of heavy clay land were treated with five tons of slaked Barbados lime per acre. The canes were grown up to third ratoons and then fallowed for a year. In the plots which were manured in addition to liming, the total increase due to liming was 37·0 tons of cane per acre, and in the unmanured plots at the rate of 33·7 tons per acre. Both the above increases refer to the sum total of ten crops harvested in 13 years.

Phosphates.—Applications of phosphates have not always resulted in financial benefit. It appears that the most satisfactory mode of using phosphates is to apply 3 cwt. of superphosphate or 5-6 cwt. of slag phosphate to plant canes, the dressings of slag phosphate being more remunerative than those of superphosphate of equal cost. Phosphates do not benefit ratoons and Prof. Harrison thinks it doubtful if it is necessary to apply phosphates to Demerara soils as often as once in five years.

Potash.—Results obtained with both sulphate and nitrate of potash indicate that potash is not required on the heavy clay soils of British Guiana under the conditions of ordinary agricultural practice.

Nitrogen.—As the mean result of ten crops of cane in 13 years it was found that 10 lbs. of nitrogen as sulphate of ammonia, when added in proportions up to 300 lbs. per acre, gave an extra return of 1·3 tons of cane per acre, or $2\frac{1}{2}$ cwt. commercial sugar. With nitrate of soda up to 250 lbs. per acre, 10 lbs. of nitrogen would probably give 1·4 tons of cane, equal to $2\frac{1}{2}$ cwt. of commercial sugar, but experiments indicate that it is not wise to apply more than 250 lbs. nitrate of soda at one dressing. With dried blood the indications over eight crops were that the relative value of nitrogen in this material was 73% of that in sulphate of ammonia.

With regard to the effect of manures on the soil, Prof. Harrison comes to the following conclusions, basing his results on the analytical figures obtained by the extraction of the soil in 1% aqueous citric acid with five hours' continuous shaking:—

“(1.) That the growth of the sugar cane without nitrogenous manuring is accompanied by a considerable loss of the nitrogen in the soil, amounting in ten years to 18·6% on not limed land, and to 26·7% on limed land. These are equivalent to losses from the soil to a depth of 8 inches of 880lbs. and 1250lbs., respectively, per acre.

“(2.) Repeated heavy dressings with farmyard manure have resulted in an increase in the total nitrogen of the soil. In ten years the increase was 20·3%, equal to 960lbs. of nitrogen per acre added to the soil to a depth of 8 inches.

“(3.) The growth of the sugar cane on plots receiving only nitrogenous manures has resulted in losses of soil nitrogen: where sulphate of ammonia was applied, the loss amounted to 14·7%, or to 670lbs. of nitrogen, and where nitrate of soda was used, to 16·3%, or to 775lbs. of nitrogen per acre, in the soil to a depth of 8 inches.

“(4.) On soils manured with phosphates, potash, and nitrogen in the form of sulphate of ammonia, the loss of soil nitrogen in the top 8 inches amounted to 14·7%, or to 700lbs. per acre, while where nitrate of soda was the source of nitrogen the loss was far higher, amounting to 26·5%, or to 1250lbs. per acre.

“(5.) The soil in 1891, at the commencement of the experiments, yielded 0·142% of phosphoric anhydride to a 1% aqueous solution of citric acid. After ten years cropping without manure it yielded 0·0086%, which shows a loss of nearly 40% of the probably available phosphoric anhydride, or of, in round figures, 170lbs. per acre.

“(6.) Where the soil received manures not containing phosphates, the proportion of probably available phosphoric anhydride was reduced to 0·0096%, equal to a loss of 32·4%, or to one of, in round figures, 140lbs. per acre.

“(7.) Where superphosphates were used in addition to nitrogenous manures, the proportion of probably available phosphoric anhydride was reduced to 0·0132%, indicating a loss of 7%, or of 30lbs. per acre.

“(8.) Where slag-phosphates had been applied, the probably available phosphoric anhydride has been reduced to 0·0102%, equal to a loss of 28·1%, or to one of 120lbs. per acre. It is worthy of note that in our more recent experiments, while manuring with slag-phosphates produced on the plots which had received superphosphates during the earlier years of the experiments mean increases of only 2·3%, they produced on those which had been manured with slag-phosphates a mean increase of 5·8%.

“(9.) The determinations of potash soluble in 1% citric acid and in 200th normal hydrochloric acid showed that cultural operations have made probably available more potash each year than is required for the growth of the sugar cane, the original samples yielding potash at the rate of 262lbs. and 278lbs. per acre to a depth of eight inches, those not manured with potash salts during ten years at the rates of

376 lbs. and 500 lbs., and those which received potash salts in addition to nitrogenous manures at the rates of 357lbs. and 530lbs.

“(10.) Judging from the solubility of the lime in the soil in 200th normal hydrochloric acid, cultural operations set free in a soluble form more lime than the crops utilised, the original soil yielding lime to the solvent at the rate of, in round figures, 3,400 lbs. per acre to a depth of eight inches, while the samples taken after ten years' cultivation yielded at the rate of 3800 lbs. The soils which received in July, 1891, slacked lime, supplying in round figures, 6700 lbs. lime per acre, yielded to the acid in 1902 a mean of 5000 lbs. per acre, thus indicating after ten years' cultural operations a retention in the uppermost layer of the soil of only 1200 lbs. of the added lime in a readily soluble form.

“(11.) The action of the lime on the solubility of the potash in the uppermost layer of the soil appeared well marked, the samples from the not-limed land yielding to 200th normal hydrochloric acid at a mean rate of 460 lbs. potash per acre to a depth of eight inches, while those from the limed land yielded at the mean rate of 640 lbs.”

Finally, as the result of these analyses and experiments, Prof. Harrison lays down certain precise and formal propositions of the greatest value to the agricultural chemist responsible for the economic manuring of large areas of sugar cane. These may be summarised as under:—

(1.) Soils which yield $\cdot 007\%$ phosphoric anhydride to 1% aqueous citric acid with five hours' continuous shaking will not as a rule respond to manurings with phosphates.

(2.) Under similar conditions soils yielding $\cdot 005\%$ - $\cdot 007\%$ will benefit as a rule by phosphatic manurings.

(3.) It is advisable to apply heavy dressings of slag-phosphates or lighter ones of super or basic phosphates to soils yielding less than $\cdot 005\%$ phosphoric anhydride.

(4.) Soils yielding $\cdot 008\%$ potash can be regarded as containing under the usual system of cultivation sufficient available potash for the needs of the sugar cane.

(5.) If the potash lies between $\cdot 005\%$ and $\cdot 008\%$ it is doubtful if the application of potash salts will result in remunerative returns.

(6.) Where the potash falls below $\cdot 005\%$ it is advisable to add potash salts in the manures.

(7.) The demand of the sugar cane for lime as a plant food is low, and if a soil gives up more than $\cdot 006\%$ to the 1% citric acid solution, it probably will yield sufficient for plant food for ordinary crops of sugar cane.

ADDENDUM TO CHAPTER XXI.

Since the above chapter was in type Mr. Francis Watts and Mr. H. A. Tempany have published (*West Indian Bulletin*, Vol. VI. No. 1) the results of experiments on the polarimetric determination of sugar.

They found that when 26·048 grams of sugar were dissolved in 100 true cubic centimetres at 30° C., readings of 99·745 and 99·78 were obtained. These readings are corrected for change of volume, corresponding to the different temperatures at which the solutions were made up and observed.

Applying Jobin's correction, they show that these readings become 99·933 and 99·975, and that when the correction connecting Mohr's c.c. and true c.c. is applied the readings become 99·705 and 99·748.

They attribute this difference to the decrease in the optical activity of sugar with rise of temperature and conclude that changes of temperature (up to about 30° C.) cause a lowering of the reading on the Ventzke scale which may be corrected by the formula: Polarisation + ($\cdot 00023 t$) N , where t is the difference of temperature of observation from that at which the instrument was standardised, and N is the scale reading observed.

For solutions requiring no clarifying re-agents they recommend:—

The solution of 26 grams of sugar in 100 true cubic centimetres. (This is equivalent to 26·048 in 100 Mohr's cubic centimetres.)

The correction quartz change by Jobin's formula, and the correction "sucrose change" by the above formula, Polarisation + ($\cdot 00023 t$) N , or combining the two, Polarisation + ($\cdot 00039 t$) N .

In the same paper they discuss the effect of the volume of the lead precipitate and show that it is not negligible, although under tropical conditions the positive error introduced by this factor may balance the negative errors already mentioned.

They call attention, however, to the method of clarifying with anhydrous basic lead acetate introduced by A. D. Horne, where the solution is completed to 100 c.c. before clarification, which is effected by the addition of a minimum of the re-agent. The accuracy of the method depends on the assumption that, provided no excess is used, the volume of the sugar solution does not change, and the analyses they adduce, demonstrate the validity of this assumption.

Finally, instead of trusting to the compensating effect of a number of errors, to obtain accurate results, they recommend this method of clarification combined with the temperature corrections detailed above.

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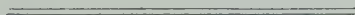
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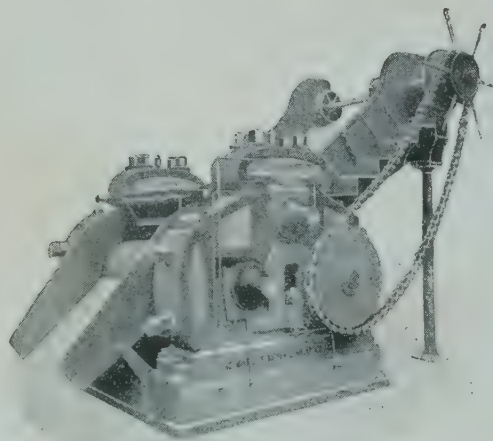
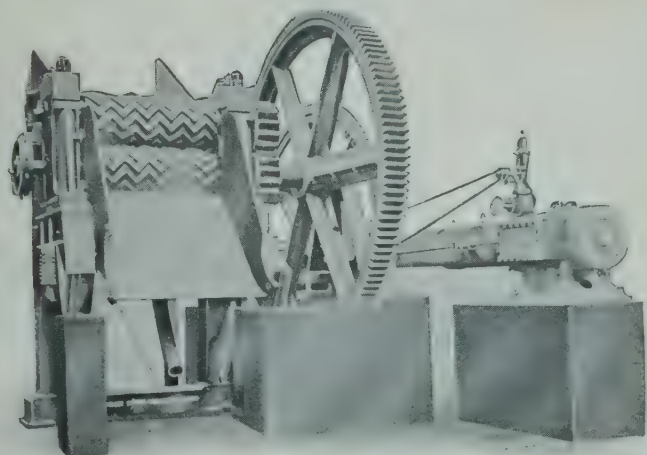
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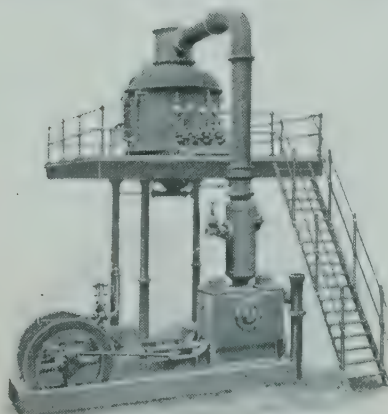
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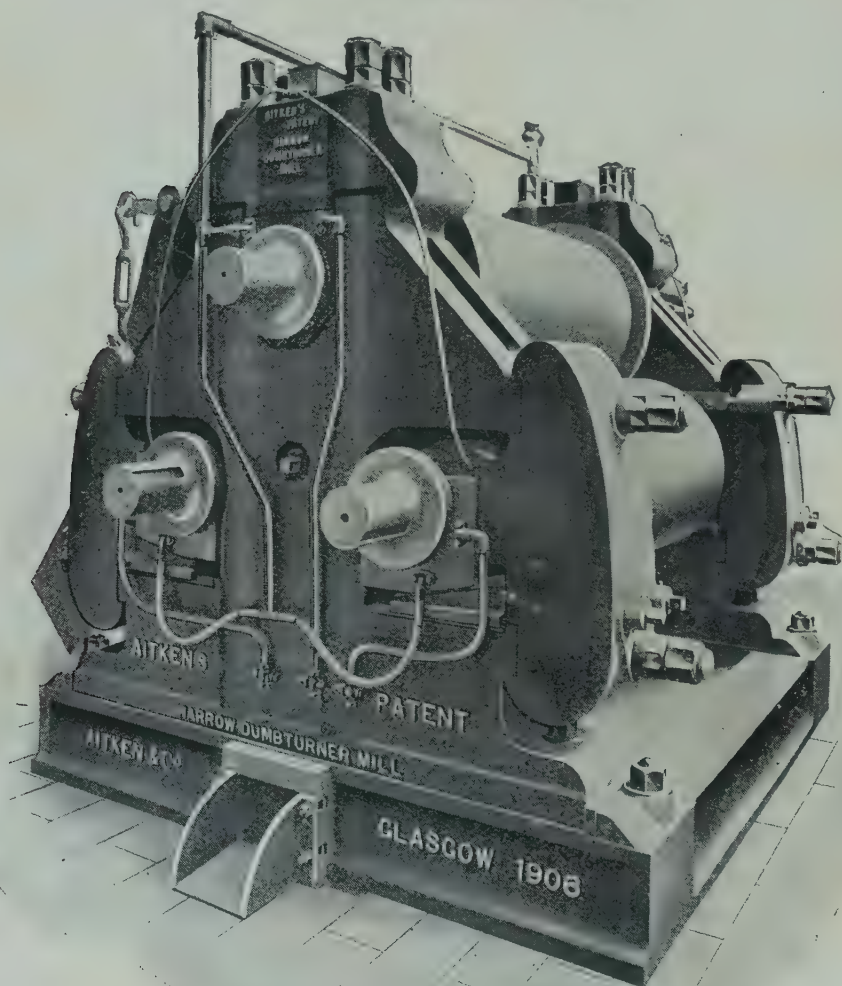
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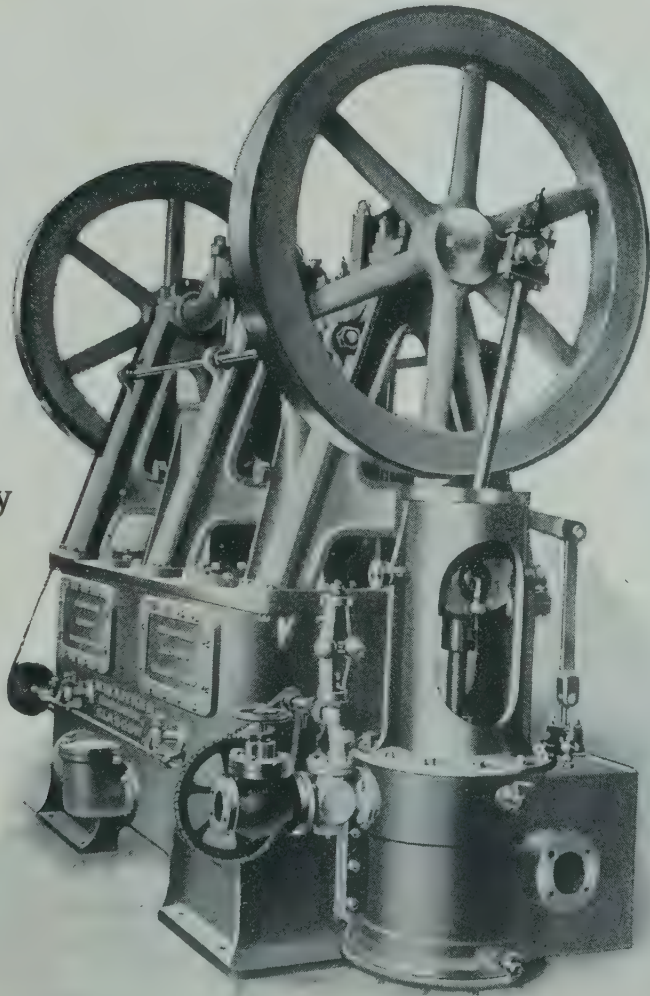
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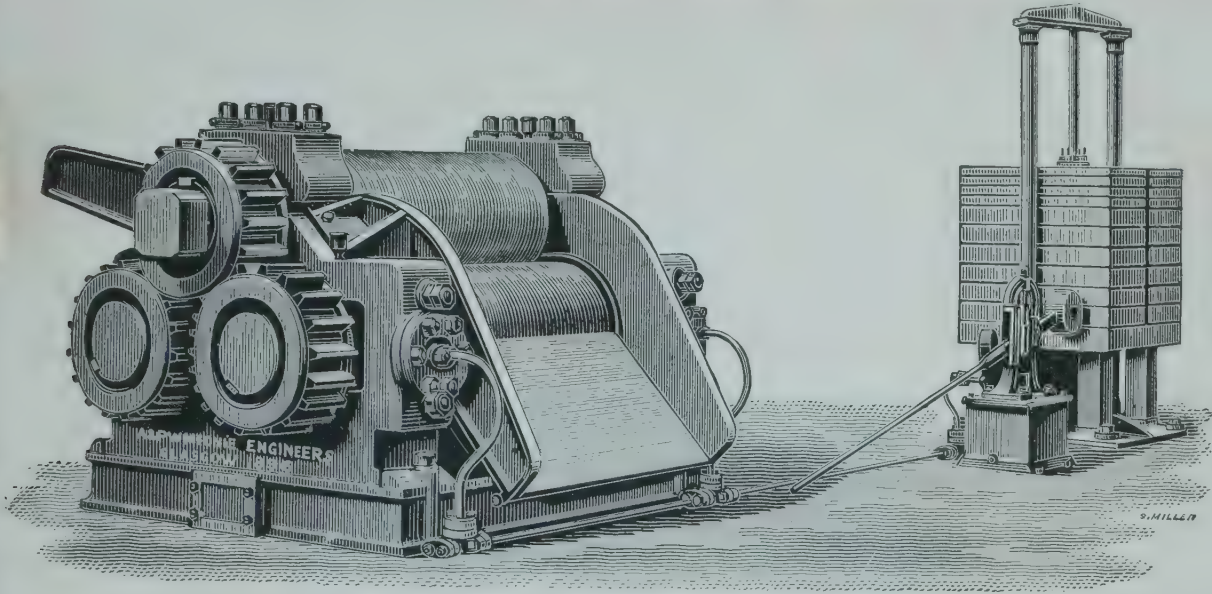
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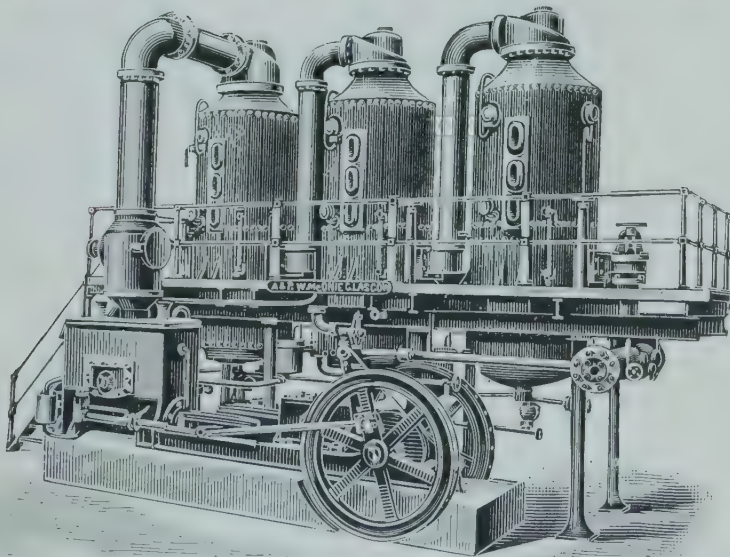


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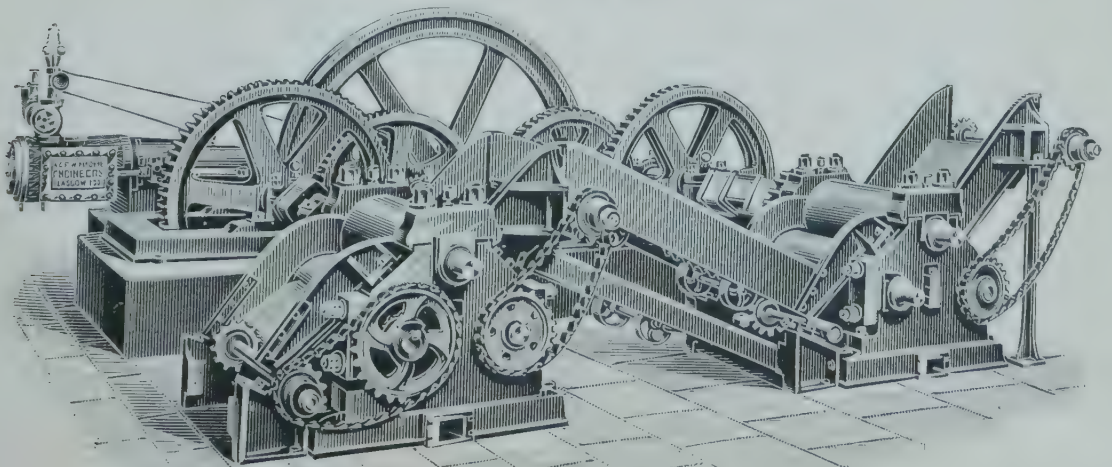
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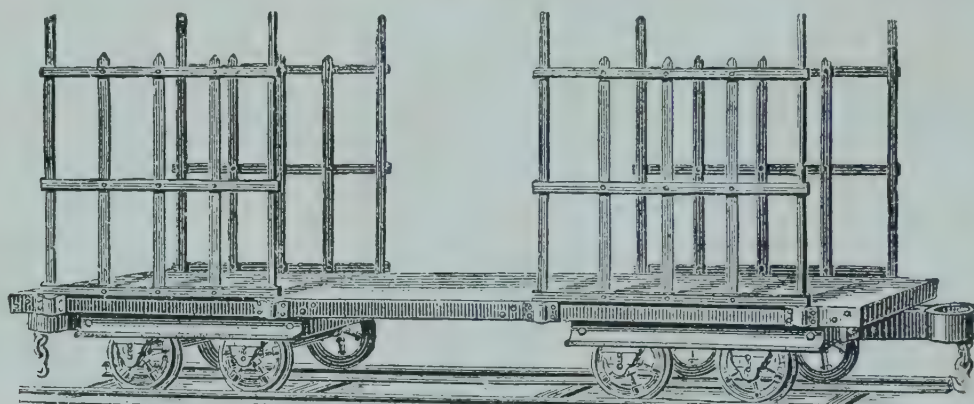
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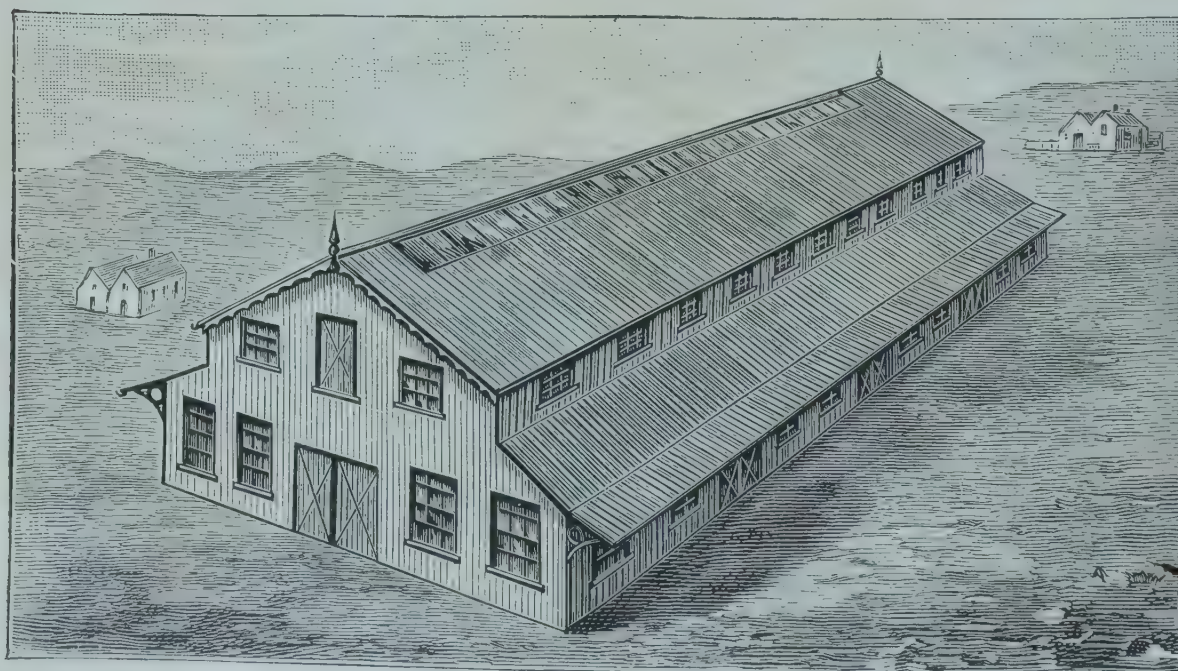
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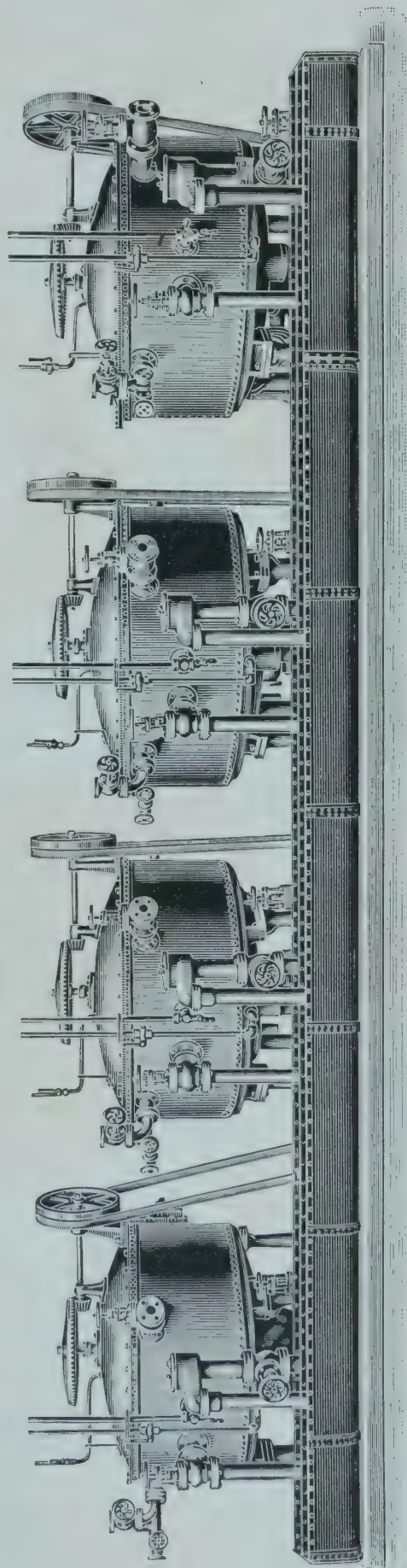
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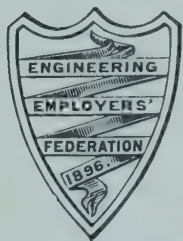
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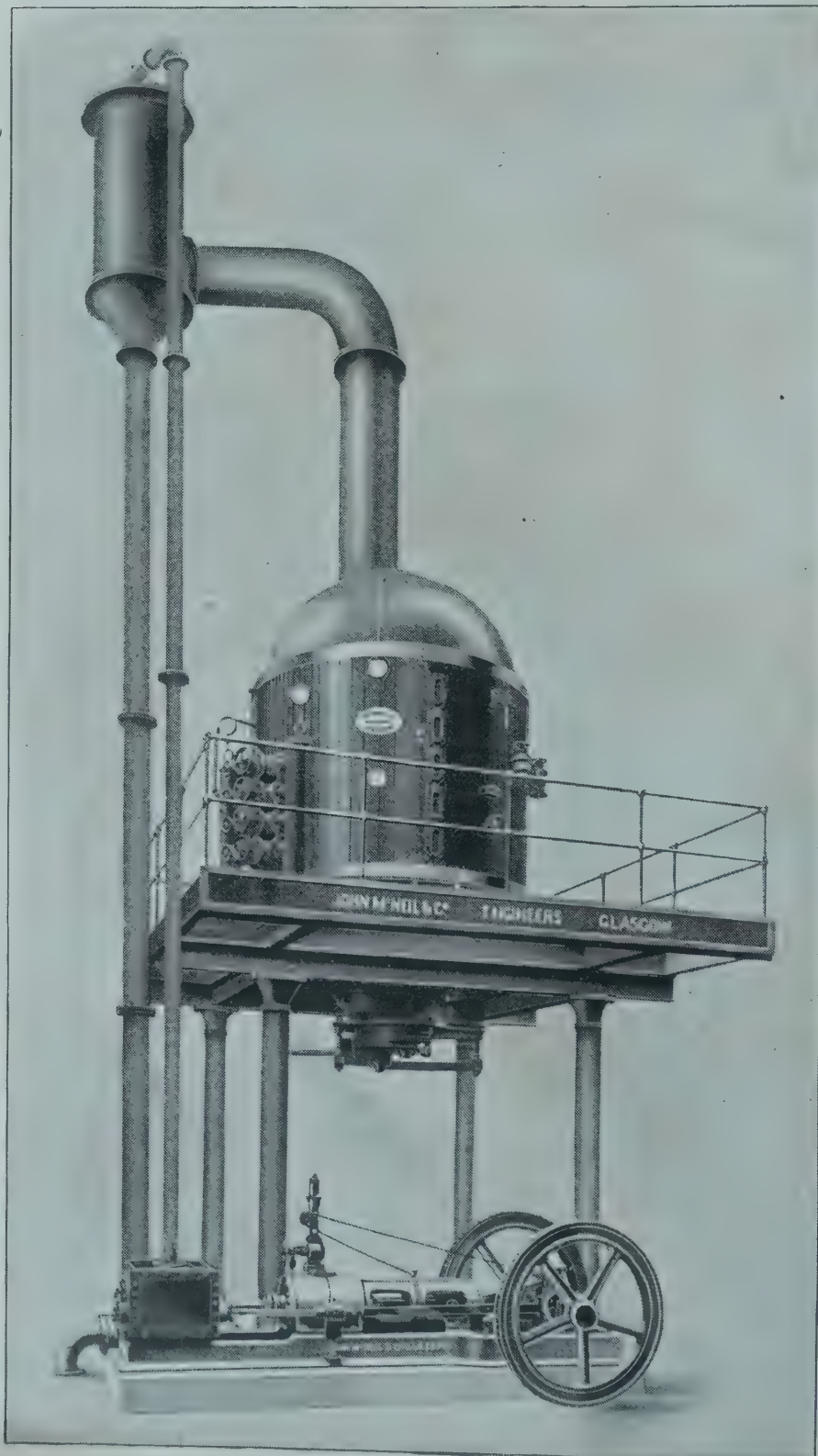


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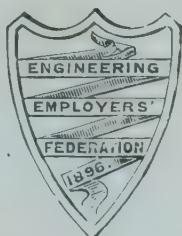
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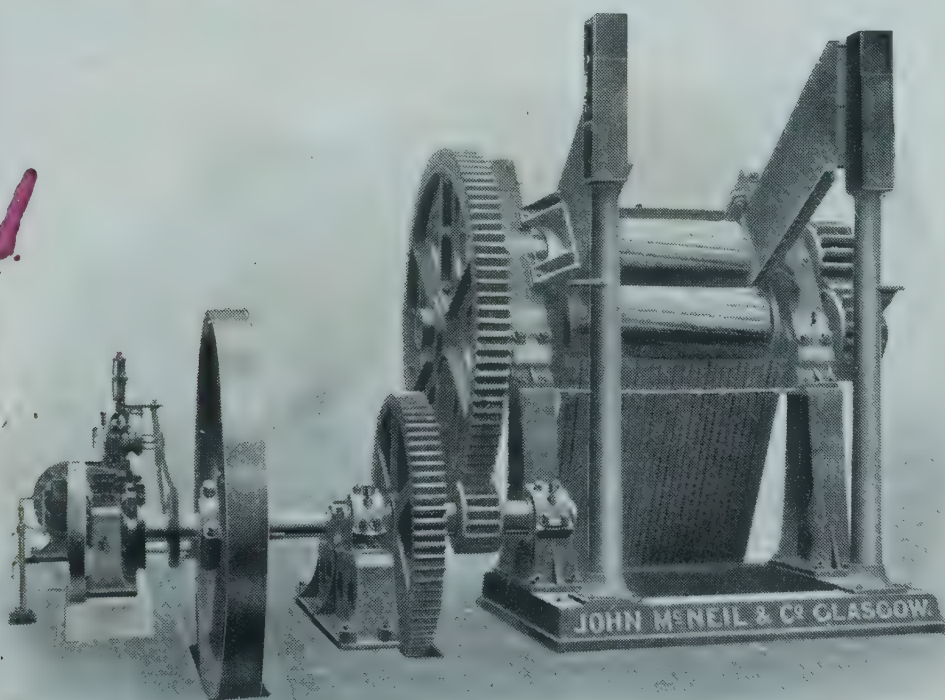
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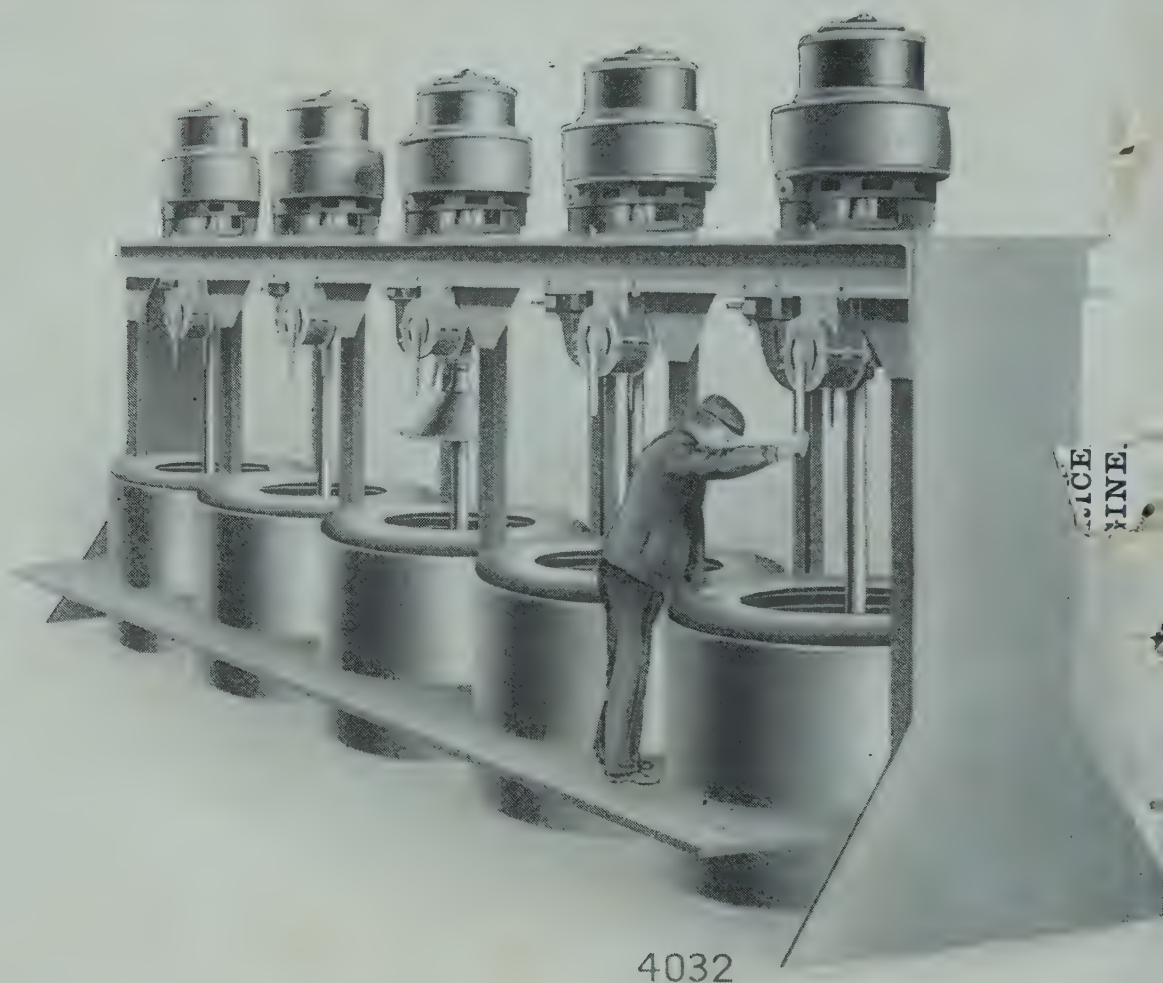
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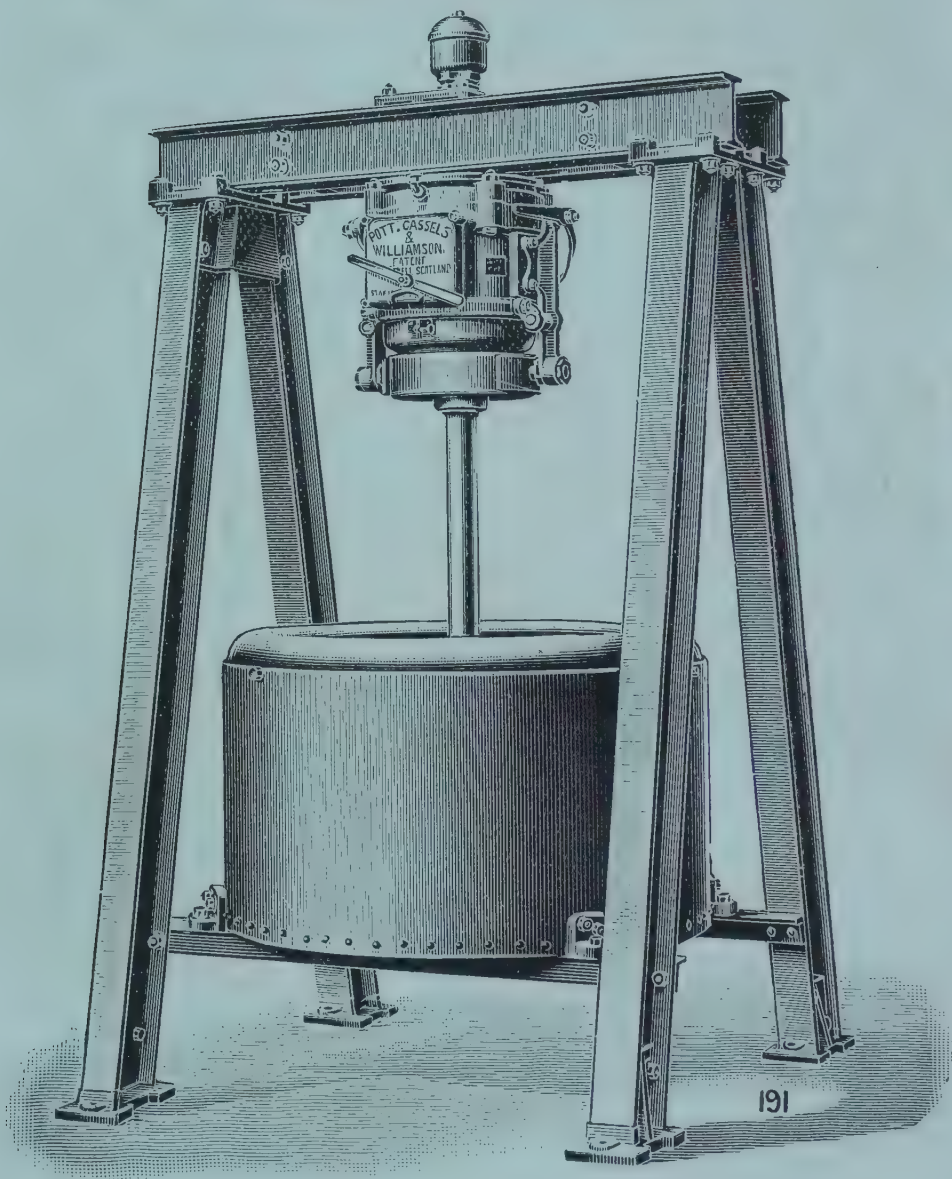
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